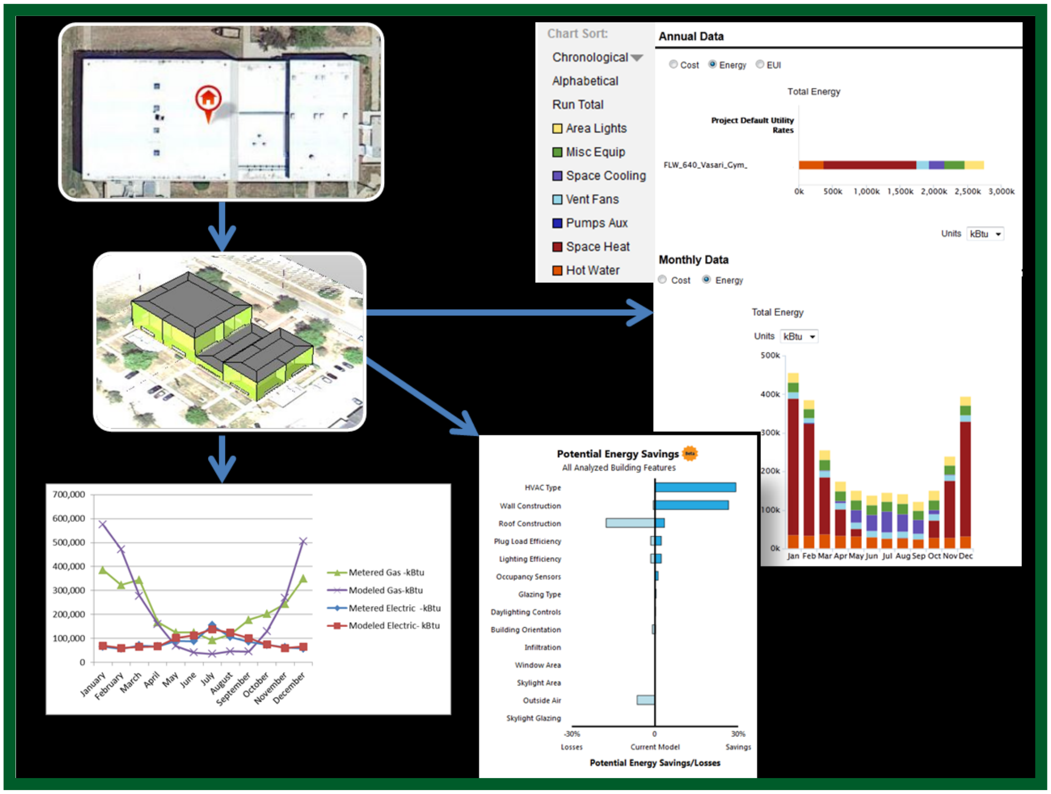
ESTCP
Cost and Performance Report

(EW-201259)



RAPID ENERGY MODELING WORKFLOW DEMONSTRATION PROJECT

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ESTCP

ENVIRONMENTAL SECURITY
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ACRONYMS AND ABBREVIATIONS

3D	three-dimensional
AFB	Air Force Base
AMI	Advanced Metering Initiative
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BIM	Building Information Model
BLCC	building life cycle costs
BPA	Building Performance Analysis
CAD	computer assisted drawing
CBECS	Commercial Building Energy Consumption Survey
COTS	commercial-off-the-shelf
CoV	Coefficient of Variation
CRADA	Cooperative Research and Development Agreement
CVRMSE	Coefficient of Variation of the Root Mean Square Error
DMLSS	Defense Medical Logistics Standard Support System
DoD	Department of Defense
DOE	Department of Energy
DOE 2.2	Department of Energy 2.2 (the simulation engine contained within Autodesk GBS)
ECM	Energy Conservation Measure
EIA	Energy Information Administration
EISA	Energy Independence Security Act
EPD	equipment power density
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESTCP	Environmental Security Technology Certification Program
EUI	Energy Use Intensity
ft^2	square foot/feet
GBS	Green Building Studio
GSF	gross square foot
HVAC	heating, ventilation and air conditioning
IESNA	Illuminating Engineering Society of North America
IT	Information Technology
kBtu	Thousand British Thermal Units
kWh	Kilowatt hours

LEED	Leadership in Energy and Environmental Design™
LPD	lighting power density
MAPE	mean absolute percentage error
MBE	mean bias error
PES	Potential Energy Savings
POC	point of contact
REM	Rapid Energy Modeling
USACE	U.S. Army Corps of Engineers
VAV	Variable Air Volume

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EXECUTIVE SUMMARY

Department of Defense (DoD) energy success is measured against mandated goals for energy reduction and sustainable facility management. In order to make consistent and well-informed decisions across its entire portfolio of buildings, DoD has a critical need for a consistent, scalable approach to evaluating energy consumption of existing facilities, to compare tradeoffs between energy conservation measures, and to identify facilities that are in greatest need of improvement.

In the last several years, it has become increasingly evident that existing methods of simulating and estimating energy use in buildings require highly trained engineers to spend significant time constructing energy analysis simulations. Shortcomings of past approaches included labor-intensive data inputs, the need for subject matter experts to operate the modeling systems, and the inability to model the DoD building inventory in a timely or cost effective way. Autodesk began looking at ways to combine various data collection methods, best practices and software tools to address this problem, and the idea of Rapid Energy Modeling (REM) was conceived.

Overall, the goal of the demonstration was to evaluate REM workflows and performance by comparing simulated to actual building energy consumption and investigate the scalability of REM workflows for the DoD. This project demonstrated that the REM workflow quickly captures and utilizes information on operations, geometry, orientation, weather, and materials, generating Three-Dimensional (3D) Building Information Models (BIM) guided by satellite views of building footprints and simulating energy use patterns. In addition, the project demonstrated the application of simulated Energy Conservation Measures (ECM) on a subset population of buildings to understand effective ways to reduce their energy consumption. The REM technology, including the ECM capabilities, uses whole-building energy simulation algorithms driven by the Department of Energy (DOE) 2.2 engine for energy analysis.

REM was applied to a sample of 23 DoD buildings across eight locations and representing seven building types. The simulated and actual building energy data was analyzed by energy type (electricity and natural gas) and energy use intensity (EUI) and further segregated by building type. The results show that the models for offices and specialty use buildings performed better than models for barracks, where variable occupancy did not match model assumptions.

Quantitatively, a primary performance objective was to have REM electric and natural gas estimates come within < 10% of actual utility information (90% average accuracy). Aggregate results indicate average accuracy of 81.88% for predicting electric consumption with a mean absolute percentage error of 18.12% (Table 7; Appendix B), considered to be a good forecast according to published criteria (Lewis, 1982). Natural gas and combined EUI predictions were on average 58.20% accurate and 77.56% accurate respectively, considered reasonably accurate (Table 6). The demonstration produced margins that while outside the target range, were still within the range of useful forecasting values (Table 6), with strong correlations in energy use curves for many buildings.

Qualitatively, the training completed indicates that the project meets the performance objectives showing that DoD participants can learn the workflow and begin creating and analyzing using REM in less than one day. Participants also indicate a high level of satisfaction with the REM

workflow. Preliminary results indicate that energy models can be completed in less than 3 hours after the process is learned (the performance objective was 2 days).

A significant number of considerations were uncovered that help guide the refinement of the REM process in the future, including data gathering and model sensitivity. Additionally, the quality of the DoD building meter data was not as high as expected before the start of this project and as a result, there may be discrepancies in comparison of simulations to the meter data.

While the REM process and reports do not mirror traditional audits, the workflow has potential benefits in that it can be implemented by DoD personnel directly. It is difficult to do a direct comparison to cost or time savings with traditional audits as there is not complete overlap in capabilities, but results indicate that REM can yield >90% savings in time and cost compared to traditional American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Level 2 auditing approaches, with the added benefits of computer simulation characteristic of Level 3 audits. REM analysis can be completed in less than one hour, with up to two additional hours that may be required for data collection. The modeling process requires minimal training or expertise and has been taught to DoD staff in less than one day during this demonstration project.

The results of this study indicate that REM can meet the need of the Energy Independence Security Act (EISA) 2007 data reporting requirements as well as support government policy including Executive Order 13423. REM provides the DoD with a way to quickly establish building geometry, scale energy analysis of the existing building portfolio, visualize end-use breakdowns of energy consumption, compare tradeoffs and potential energy savings between energy conservation measures automatically, identify facilities that are in greatest need of improvement, and enhance scalability of energy evaluations and retrofits.

Quantitative Benefits	**Average Accuracy Comparison to Historic Utility Information**
EUI electric average	81.88%
EUI natural gas average	58.20%
Combined EUI average	77.56%
Application of design alternatives to model potential energy savings	Energy savings greater than 30% achieved on three out of five buildings.
Time and cost to create energy models	Cost savings of over 95% and time savings of 90-95% compared to ASHRAE Level 2 audits.
Qualitative Benefits	**End User Effort**
Ease of learning REM process	Less than one day
Effort to create a REM	3 hours per building with added benefit of auto-generation of multiple simulations to explore and prioritize ECMs

1.0 INTRODUCTION

1.1 BACKGROUND

Current building energy assessment methods for existing buildings are expensive, laborious, time consuming and require a high level of technical sophistication, experience and expertise that takes years to establish. In short, typical building energy assessment methods are not scalable across a large number of buildings.

The energy consumed by facilities owned and operated by the Department of Defense (DoD) accounts for approximately 80% of the total energy used by Federal buildings (DoD, 2005). However, determining information about the energy use on military bases is challenging, as buildings historically have not been metered individually. Due to data quality issues and lack of access to information, facility managers or resource efficiency managers have difficulty managing their building energy footprints and prioritizing their energy retrofit budgets effectively.

DoD energy success is measured against mandated goals for energy reduction and sustainable facility management. In order to make consistent and well-informed decisions across its entire portfolio of buildings, DoD has a critical need for a consistent, scalable approach for evaluating energy consumption of existing facilities, to compare tradeoffs between energy conservation measures, and to identify facilities that are in greatest need of improvement.

Evaluation of baseline energy use and identification of opportunities for improved building performance are top priorities for decreasing carbon emissions, reducing energy costs and enhancing energy efficiency. Additionally, energy security and regulatory mandates are key drivers of energy efficiency retrofits across the DoD. Typical approaches for rapidly assessing and benchmarking energy usage and evaluating proposed energy retrofit measures are not precise and often fail to acknowledge the complexity of buildings and building performance. Interrelated factors, such as building orientation, location, operational use, and structural idiosyncrasies can all influence energy use and the effectiveness of retrofit decisions on reducing energy usage and energy costs. More comprehensive energy auditing techniques, such as American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) level audits are costly, time-intensive and require a high level of expertise.

To address these challenges, Autodesk executed a demonstration of Rapid Energy Modeling (REM) workflows that employed building information modeling (BIM) approaches and conceptual energy analysis. The project investigated the hypothesis that REM is a viable and scalable method for generating accurate, rapid and cost-effective estimates of energy consumption for DoD buildings. The demonstration was a pilot-scale operation over a 1-year period using a population of 35 buildings and an analyzed sample of 23 buildings.

The benefit of this technology is that it puts a viable building energy assessment method in the hands of DoD installations. On-site personnel can reasonably learn and use this approach to prioritize the energy management decisions needed at their installation. This technology can dramatically decrease the time it takes to understand the energy performance of DoD buildings.

1.2 OBJECTIVE OF THE DEMONSTRATION

The project's objective was to investigate REM to determine if the workflow is capable of producing useful, rapid and cost-effective estimates of energy consumption for DoD buildings. REM would then provide DoD numerous benefits, including the ability to: meet federal mandates, increase energy security, enhance the ability to prioritize energy efficiency retrofit projects, track energy use reductions, and manage facilities in new and cost-effective ways.

The overarching objective of the field demonstration was to provide lightweight BIMs and an easily scalable REM methodology for estimating energy intensity in DoD buildings, identifying buildings that would be most responsive to improvements and exploring various Energy Conservation Measures (ECM) for buildings. The technology demonstrated included a workflow for creating digital, three-dimensional (3D) models of buildings from publicly available satellite or aerial imagery. The process captures existing building geometry, appends operational characteristics as well as local weather data to generate 3D models to estimate the energy use of the modeled buildings. The research objectives in this demonstration include a comparison of the REM generated energy use simulations to historical metered data. This validation was carried out to provide confidence in the REM methodology. Also validated are the time and cost to produce results with this REM approach as well a comparison of cost requirements for other approaches such as energy auditing. In addition, this demonstration validated the acceptance and use of the REM technology by DoD personnel at installations.

1.3 REGULATORY DRIVERS

The following existing or anticipated federal, state, or local regulations or DoD directives have resulted in a need for a new technology such as REM:

- *Energy Policy Act* (2005) – Requires that federal buildings be metered "*to the maximum extent practicable.*" Despite the mandate, the majority of DoD buildings are still without meters. REM processes can help the DoD evaluate and benchmark energy use in buildings, assist in determining which buildings are practical to meter, identify buildings with meters that are not functioning well, and identify poorly performing buildings.
- *Energy Independence and Security Act of 2007* (EISA, 2007) – Sets a target for the government to reduce its energy and other resource consumption by 30% by 2015 compared to a 2003 baseline. Additionally, EISA calls for energy and water audits for 25% of facilities annually and all appropriate facilities on a 4-year cycle (AEMR, 2010). Using REM processes, the project team conducted rapid audits of DoD buildings and investigated ECMs to achieve reductions in energy use on a subset of five buildings.
- *Executive Order 13423 Strengthening Federal Environmental, Energy, and Transportation Management* (2007) – Encourages continuous improvement in the areas of energy efficiency, renewable energy, water conservation, and sustainable building. Models produced through the REM process can be updated and accessed continually, thus allowing energy managers to continuously explore energy saving and energy generation opportunities.

- *Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings* – Calls for 30% reduction in energy costs for new construction and 20% reduction in major renovations. REM processes can be used to investigate renovations to meet these energy cost reduction targets and provide a higher level of customization than benchmarking without the time and cost associated with ASHRAE or investment-grade energy audits.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The demonstration defines a process to capture existing building geometry using satellite photos. The operational characteristics of the building are appended to the geometric model and local weather data to generate energy models that can quickly predict the energy use of the modeled buildings. This information can help asset managers determine which buildings are performing poorly compared to predicted energy use.

The REM process involves the following technologies (Figure 1):

- Autodesk® FormIt software is an iOS and Android operating system application to create 3D models. FormIt captures existing building conditions using satellite images from Google and allows users to create a 3D geo-referenced building model while in the field.
- Autodesk® Revit is a BIM software application with integrated energy and carbon analyses driven by Green Building Studio (GBS) and Department of Energy (DOE) 2.2.
- Autodesk® Vasari software is for creating building conceptual models, with integrated energy and carbon analyses driven by GBS and DOE 2.2.
- Autodesk® GBS is a web service that performs whole building energy analysis using the DOE 2.2 engine.

The REM workflow involves three stages involving: (1) capture of existing conditions, (2) conceptual modeling of building masses using FormIt, Revit and Vasari, and (3) comparative analysis. The energy results of these building analyses are represented as annual energy use for natural gas and electric, monthly and annual cost, monthly energy use and energy use intensity (EUI) (Figure 1).

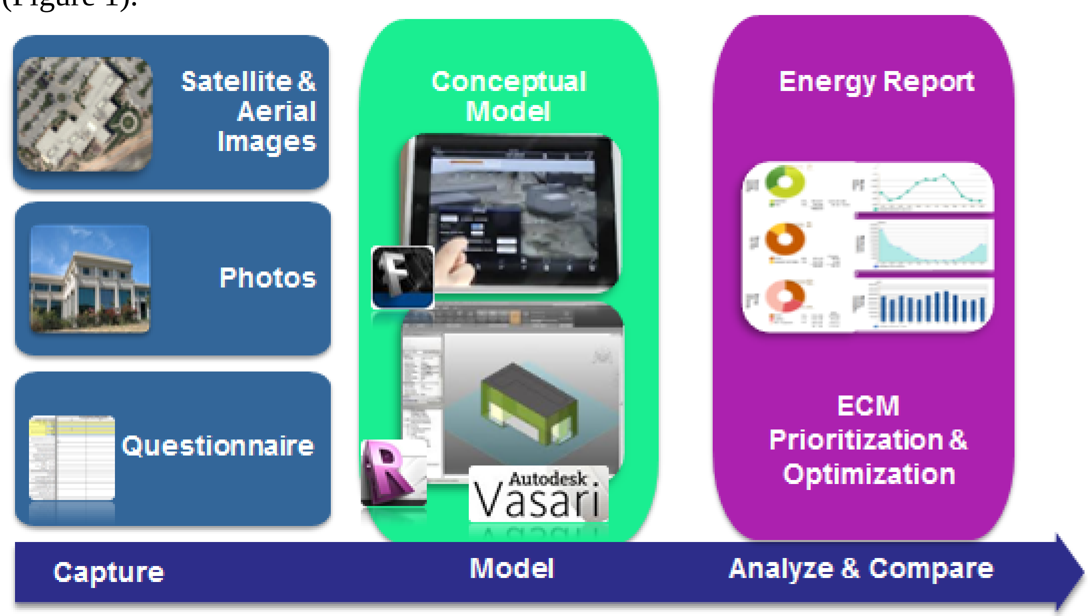

Figure 1. REM Technology Components.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Current methods and high costs for energy audits may limit their practicality for implementation across the DoD, and less expensive benchmarking approaches, such as Energy Star and Commercial Building Energy Consumption Survey (CBECS), do not provide building-specific detail or identify opportunities for savings.

Alternative technologies include several energy modeling graphical user interface front ends to generate building geometry and apply energy modeling attributes. It was beyond the scope of this project to understand the relative technical merits of these applications. Several of these alternatives are available from the DOE (NREL, 2013).

The REM workflow for energy assessments can provide advantages by offering a level of detail not obtained through benchmarking and with significantly less cost than energy audits. A limitation is that REM does not provide the detail of investment grade energy audits and does not cover some aspects of a Level 2 energy audit (such as equipment inventories and estimating costs for ECMs), although it does include computer simulation often part of Level 3 audits. The detailed attributes typically required for the Level 1 or 2 energy audits are not based on an understanding of the relative sensitivity of these attributes to energy model performance, so it is difficult to say how much of a limitation it is to simply allow some attributes to be defined with default values. Where full data for the building is not available, intelligent defaults are used based on ASHRAE, extensive background from CBECS, research papers, and expert systems developed by energy modeling professionals.

REM is useful in developing a starting point in understanding how the studied building is operating using a model derived from a large set of existing buildings that are operating correctly. Having an understanding of the building energy sensitivities and how building energy use differs from typical buildings allows one to focus the energy conservation work; evaluators can look at their portfolio to find outliers; or users can use prioritize retrofit budget where it is needed most.

Several inputs to the energy model are driven by observations from satellite/aerial imagery and survey responses from building managers. Building and operational attributes of a particular building not properly identified can impact modeling results. This is not a limitation with REM, but a general limitation with simulation in general.

Accurate modeling of building systems is an important factor in developing useful energy models. The downside to focusing on these building systems and their operation is that they add a high level of detail to a process whose goal is to remain rapid and agile. Engineers and energy analysts who want to do more detailed analyses can move REM data to eQuest or EnergyPlus for detailed work in those tools, which may require more expertise and detailed inputs. Constructing the initial model using REM can yield substantial timesavings versus initial model creation in eQuest or Energy Plus tools (Schneider, 2011).

3.0 PERFORMANCE OBJECTIVES

Table 1. Performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Correlation of REM with annual energy electricity and fuel intensity	kWh and therms	Utility history and/or energy meter data (compared to gbXML model data)	Annual electric and natural gas energy +/-10% compared to baseline historical utility data Annual electric and natural gas within good to reasonable prediction levels as defined in literature.	• Results were within 10% error on 7 out of 25 buildings for electric. Two buildings fell within +/-10% for natural gas. Overall, there was 81.88% average accuracy for electric (18.12% MAPE). • Models for electric use in office buildings performed better than models for barracks or specialty use buildings, with 85.70% average accuracy (14.30% MAPE). Accuracy for natural gas averaged 58.2% (41.80% MAPE). • Principle reasons for deviations could be related to flawed meter data, weather anomalies, occupancy variations in building usage, or interior space utilization differences (see 8.0). • Also, deviations may point to operational inefficiencies that should be addressed through re-commissioning for energy and cost savings. • Although not within 10% error, electric MAPE values were within the 11-20% threshold, considered "good." Forecasts of natural gas usage at 41.80% MAPE were within 21%-50%, considered reasonable (Lewis, 1982; Chen et al., 2008)
Correlation of REM with overall annual EUI	kBtu/ft²	Utility history and/or energy meter data (compared to gbXML model data)	Annual Energy Intensity +/-25% compared to baseline historical utility data Annual EUI predictions within good to reasonable levels as defined in literature.	• 14 out of 25 buildings were within +/- 25% MBE in predicting overall EUI. Average accuracy was 77.56% (MAPE of 22.44%) • MAPE results fall within the 21%-50% threshold, considered reasonable. As above, deviations may be related to inaccurate meter data, operational inefficiencies, weather anomalies, or space utilization.

kWh = kilowatt hours
MAPE = mean absolute percentage error
kBtu = thousand British thermal units
ft2 = square feet
MBE = mean bias error

Table 1. Performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives (continued)				
Variance in monthly consumption (billing history)	%	Utility rates, energy meter data and modeled energy data for each building	Acceptable values are a coefficient of variation (CoV) of the root mean squared error (CVRMSE) of $\leq$ 15%.	• Results were within 15% CVRMSE for a total of three buildings using billing history and cost as metrics. An additional two buildings were within 20% CVRMSE. • Additional simulation runs did not attempt to tune the modeled results to match metered values, but the CVRMSE provides a snapshot of how baseline models aligned with metered data. • It was not anticipated that initial models would align within 15%, as this is the standard that calibrated models are working towards and is outside of REM intent. Buildings with the closest calibration were selected for exploration of design alternatives for ECMs.
Testing the REM process for design alternatives to model PES	% energy savings in kWh and therms	gbXML file and GBS design files	Design strategies will attempt to achieve energy savings greater than 30%	• ECMs explored basic and advanced design strategies for five buildings. Savings greater than 30% was achieved on three out of the five buildings. • The two buildings that did not achieve the target already had undergone energy retrofits, which were reflected in the models.
Qualitative Performance Objectives				
Ease of learning technology and expertise required to create REM models	Person hours of training to complete building models	Training Curriculum; Hours required for successful completion of REM training program.	On average < 6 days to learn technology and complete 1st building model and generate an energy report. After successful completion of first REM on average < 2 days per building to complete models and generate reports.	The 1 year of technology transition has not yet passed, however preliminary results indicate that energy models can be completed in less than 3 hours after the process is learned.
User Satisfaction	Satisfaction with REM workflow and processes	Responses from informal interviews and anecdotal observations	Users are generally satisfied with the REM process, tools, and results	Participants indicate a high level of satisfaction with the workflow.
Ability to scale process across the DoD	Number of REM trained personnel at end of pilot study	Participants active in training program and completion of training	Five individuals trained and independently creating REM models at completion of first year of technology transition.	At this point in time, three individuals have received training, with others scheduled for training in the future.

CoV = coefficient of variation
CVRMSE = Coefficient of Variation of the Root Mean Square Error
PES = potential energy savings

4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Researchers visited a total of 10 installations across six climate zones (Figure 2) between December 2012 – March 2013, and selected 23 buildings for inclusion in the core analysis of the study.

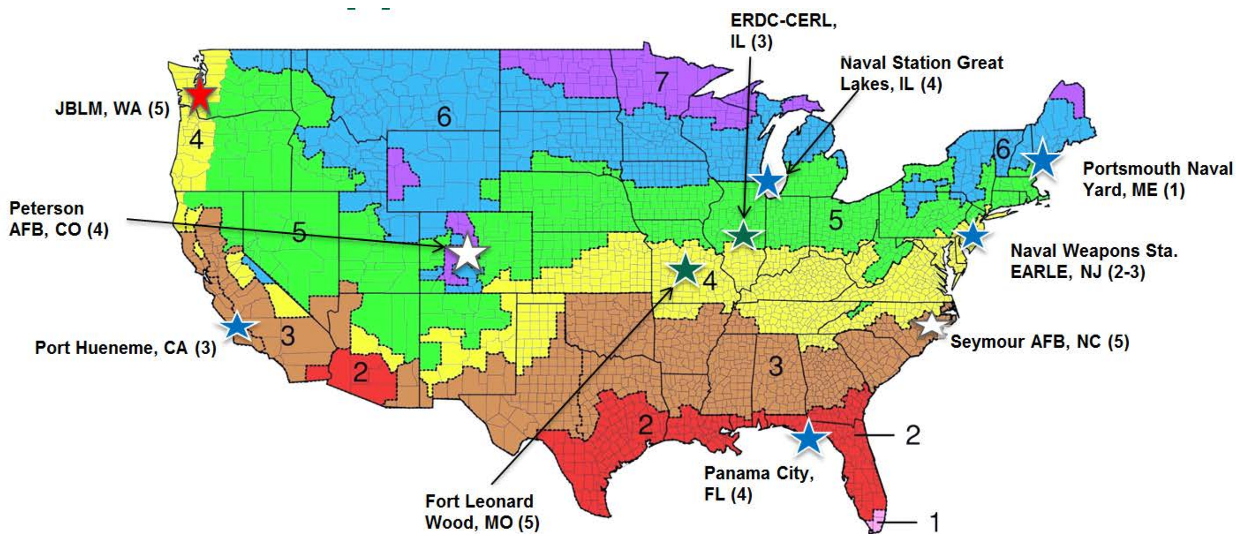

Figure 2. Site locations.

4.2 FACILITY/SITE CONDITIONS

Prior to scheduling the site visits, researchers received verification that meter data was complete and usable by Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), a partner on this project working via a Cooperative Research and Development Agreement (CRADA) set up for this project. Site visits included engagement with the installation point of contact (POC) and review of the completed energy questionnaire. The research did not interfere with ongoing operations.

Table 2. Site information.

Installation	Buildings	Installation	Buildings
ERDC-CERL	3 Offices	Port Hueneme	4 Offices (3 excluded)
Fort Leonard Wood	1 Office; 3 Barracks (1 excluded from analysis), 1 Gym	Portsmouth	1 Barracks
Joint Base Lewis McChord	2 Offices (1 excluded); 2 Barracks (1 excluded)	Seymour AFB	1 Office; 1 Cafeteria; 1 School; 1 Fire station; 1 Automotive Facility
Panama City	2 Offices; 1 Barracks	Earle Naval Weapons Station	1 Office; 1 Auto Facility; 1 Cafeteria (all excluded)
Peterson AFB	4 Offices	Great Lakes	2 Barracks; 1 Drill Hall (all excluded)

AFB = Air Force Base

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5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

This project evaluated technical performance and cost characteristics of estimating energy consumption of buildings by conducting REM simulations. These simulations were then compared blindly to historical energy use information of the same studied buildings. A subset of five buildings was further processed with the design alternatives capabilities of REM software tools in order to estimate how much energy could be saved by applying ECMs. Design alternatives were selected for each of the five buildings by the project team and simulation estimates are included in this report. The test phases are described in Table 3.

Table 3. Test phases.

Test Phase	Activity
Reality capture	Identification of 35 candidate facilities of various types in different locations; reduced the number to 23 buildings for aggregate analysis because of meter data quality concerns. Energy questionnaire collection. Meter data validation by ERDC-CERL. Candidate buildings identified on satellite and verified by installation POCs. Site visit for reference photos and clarification on questionnaire responses.
Model	Used FormIt conceptual modeler in the field to create 3D building model, refined the model in Revit based on energy survey, site observations, and reference photos. Vasari workflow explored a remote approach using software-integrated satellite imagery and the energy survey. Generated energy models based on conceptual model building location, geometry, energy settings, ASHRAE defaults where energy settings were not provided, and weather information. Performed Conceptual Energy Analysis driven by GBS/DOE 2.2 engine. Produced energy reports.
Analyze	Compared modeled results to actual utility meter data and to benchmarking results using CBECS. Compared REM to time and cost of audits. Reviewed the energy analysis findings under the High Performance and Sustainable Building Guiding Principles Compliance Pathways for building efficiency and sustainability goals for CVRMSE, using billing rates. Five of the study's 23 buildings that were within an acceptable tolerance of CVRMSE calibration were further processed with the design alternatives capabilities of GBS, informed by PES analysis across a range of building parameters.
Technology transfer & reporting	Workshop, Webinar and Curriculum Development. Report development and submission.

5.2 BASELINE CHARACTERIZATION

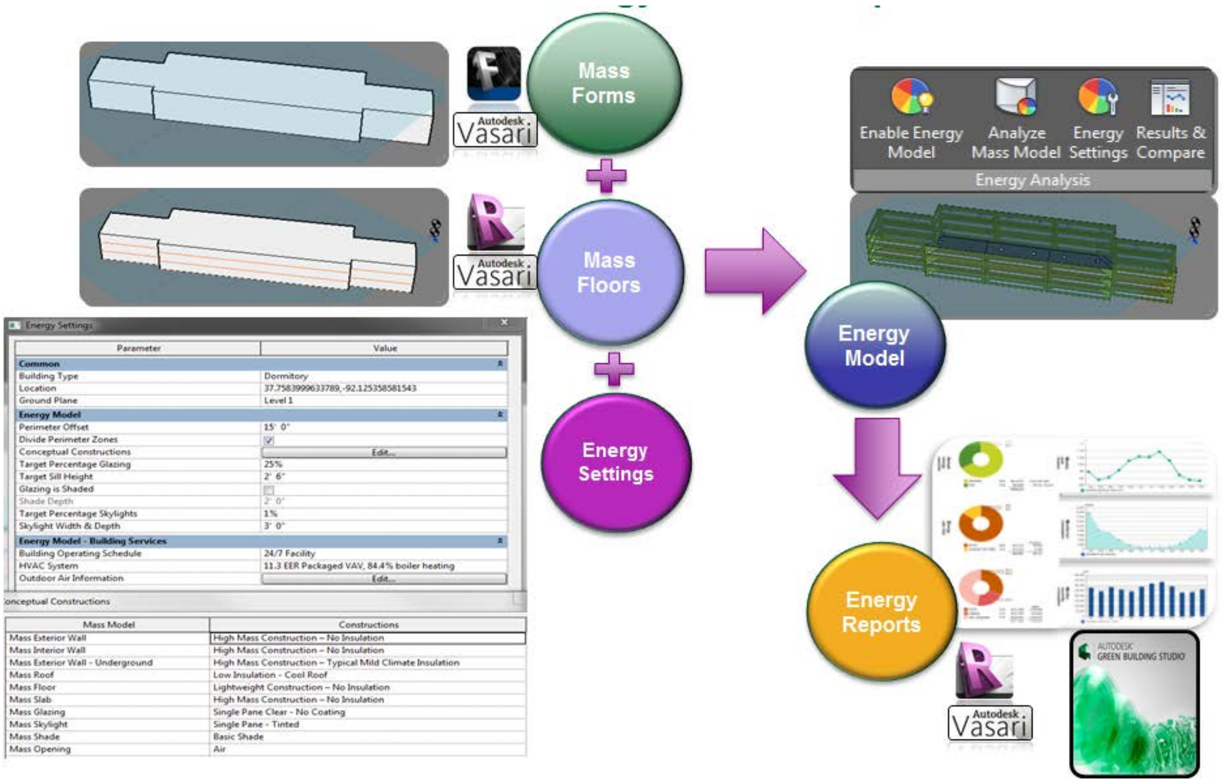
The historical metering data was used as a reference condition to determine the technical performance accuracy of the REM method and the existence of historical natural gas and electric metering information was a prerequisite for a building to participate in this study. ERDC-CERL requested building natural gas and electric meter data at the most granular level available from candidate installations. CERL then conducted a review of this data to ensure that, at minimum, there were 12 months of reliable natural gas and electric meter data for each building.

The inputs for the energy model were derived using imagery and responses to the site survey, and focused on rapid baseline characterization of the building geometry, operations and systems. The REM workflow also does not utilize floorplans or model interior walls, opting instead for ASHRAE standard perimeter-core space simplification and a maximum width of perimeter zone to minimize the error introduced by removing interior partitions. The REM models also do not designate different space utilizations within a building, so buildings with different space utilizations (i.e., office and lab) are modeled as one building type per generalizations similar to the building-wide defaults recommended in ASHRAE 90.1 vs. the space-by-space method. Accurate modeling of interior spaces is possible with the software tools, however this requires a significant time investment to collect, organize, and translate building plans into the model, and would require additional expertise from DoD end users that is not of sufficient value for the purposes of a REM survey. Similarly, building schedules may not be uniform throughout the building, or consistent on a weekly, monthly or annual basis. Researchers used information provided by installation staff to determine schedule selection in the modeling and energy analysis tools. Several installations provided monthly totals instead of interval meter data as requested, thus in these cases, few insights regarding accuracy of schedule assumptions could be gleaned. It was assumed that weather for the year of meter data submitted was not anomalous.

Some installations submitted monthly interval data, while others submitted 15 minute interval data. Several buildings were eliminated during this validation stage, due to apparent issues with the meter data. Other datasets were validated and included in the study, only to have the meter data later determined to be unreliable when released from ERDC-CERL to Autodesk for comparison with REM results. Several buildings included in the study have meter data anomalies, such as large spikes in usage that may or may not be accurate (see Appendix C). Additionally, modeled energy results, and metered data were compared to the DOE Index for Commercial Buildings, which utilizes data from the Energy Information Administration (EIA) 2003 CBECS using the Building Energy Data Book tool. Primary search criteria were climate zone and building type, followed by size and vintage, if sample sizes were sufficient ($n>10$) to allow further refinement.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Researchers explored the various software tools and workflows to better assess capabilities and then optimize scalability for DoD when technology is transferred (see section 2.1). Some of the tools have overlap in terms of their functional attributes, and the portability of file formats between tools allows users a great deal flexibility in determining a workflow (Figure 3) depending on the level of detail desired, expertise, and time constraints (See Section 6.5 for discussion of attributes of workflows.)



In the REM workflow, the mass form geometry is created using satellite imagery. Mass floors are then created to reflect the number of levels and floor to floor heights of the building, which are informed by the questionnaire responses and satellite images (See Section 5.1). Energy settings are then selected based on questionnaire information or satellite information in the case where supplied information is inadequate. The energy model is then enabled and zoning is created based on ASHRAE. The energy model report is then generated in GBS. Enhanced analysis is then possible with GBS.

Figure 3. Visual depiction of DoD technical workflow.

5.4 OPERATIONAL TESTING

The relevant mode of operation is a standard methodology outlined (Table 4). The testing occurred between October 2012 and October 2013 (see Figure 13 Gantt chart in the ESTCP Final Report).

5.5 SAMPLING PROTOCOL

Table 4. Sampling Parameters and Types.

Performance Objective	Parameters	Number and Type of Samples
Correlation of REM with annual energy electricity intensity, annual fuel intensity, and overall EUI	Electricity and natural gas data from model and from meters	Minimum of 1 year of meter data information plus model data. Produced monthly and annual graphs. CBECS data included annual kBtu/ ft^2 electric, natural gas, and EUI, respectively.
Variance in monthly consumption (billing history)	Billing rates	Utility bills were unavailable. CVRMSE was calculated between monthly modeled versus metered billing costs based on utility rates provided and using monthly energy use.
Energy reduction through GBS modeling of ECMs	% energy savings in kWh and therms; cost savings in $	PES analyses within GBS were used to identify design alternatives for ECMs for five buildings. Documentation of energy and cost savings vs. model and meter data.
Time and cost to energy model	Hours or hours/ft^2; $/ ft^2	Published data in preparation for publication was used to assess average time and cost requirements for ASHRAE Level 2 audits.
Ease of learning technology and expertise required, satisfaction, scalability	Hours of training to complete initial building energy models. Satisfaction with REM workflow and processes.	Autodesk staff to optimize workflows based on experience, input requirements and constraints, conduct training with DoD personnel, gauge satisfaction and time required to learn workflow.

5.6 SAMPLING RESULTS

Table 5. Summary info on data collected.

Division	# of Buildings Visited	# of Buildings in Core Study Set	Captured Data Pre-site Visit for each Building	On Site Information for each building	Models for each building	Reports for each building
Army	8	7	• Meter data • Energy survey • Location and satellite image	• Photos of building exterior *(often non-essential)*. Reference measurement of building footprints *(non-essential)* • Clarifying questions re: energy survey	• Conceptual 3D models • GBS XML	GBS Dashboard Charts and data tables. Monthly and annual tables and graphs of modeled results plotted in relation to results from building meters.
Navy	14	5				
Air Force	9	9				
Joint	4	2				
Total	35	23 *(12 removed due to data issues)*				

6.0 PERFORMANCE ASSESSMENT

Data collected during the demonstration provides information necessary to assess the effectiveness of REM relative to the performance objectives defined in Table 1. The following is a summary of the analysis in support of the performance objectives.

6.1 OVERALL CORRELATION OF MODELED RESULTS TO METER DATA

These measures quantified the effectiveness of REM to estimate natural gas, electric and overall energy usage of individual buildings within 10% error compared to meter data provided by the installation. Prior case studies that guided establishment of the 10% error targeted traditional commercial office buildings with standard operating hours and usage. DoD buildings in the sample vary widely in their occupancy and usage and a re-established success criteria of <20% error is a better metric to evaluate forecast accuracy. Forecast performance was assessed using MBE and MAPE. Lewis's interpretation of MAPE results (1982) is criteria used to judge the accuracy of the forecast and is summarized in Table 6.

Table 6. Typical MAPE values for model evaluation.

MAPE (%)	Evaluation
MAPE # 10%	High accuracy forecasting
10% < MAPE # 20%	Good forecasting
20% < MAPE # 50%	Reasonable forecasting
MAPE > 50%	Inaccurate forecasting

Source: Lewis (1982)

Energy use is a frequently tracked metric for many buildings, yet there are many buildings that do not have meters installed, meters are not functioning, and or data is not usable (see list of meter-related issues in Section 8.0). REM predicts how buildings should be performing (or where buildings are potentially used in non-standard ways), *based* on their use profile, unique geometry, generalized use schedules, and location and construction characteristics for buildings of their type and region. Where model input parameters are not known, many sources are used to define defaults based on CBECS, design tables within ASHRAE/Illuminating Engineering Society of North America (IESNA) Standard 90.1-2004, scientific research papers and modeling best practices. This provides a rational baseline of information from which to make asset management decisions.

The models predicted energy usage using GBS, driven by the DOE 2.2 engine. Meter data received from the installations was reviewed by a third party (ERDC-CERL) prior to comparison with modeled estimates. In some cases, despite verification, subsequent issues were encountered with the meter data that required removal from the study or aspects of the analysis. Of a population of 35 buildings, a total of 23 buildings were included in core analyses. A total of 12 buildings were excluded from core analyses due to:

- Questionable meter data and scaling issues – three Earle Naval Weapons Station buildings and one Joint Base Lewis McChord building

- Building occupancy concerns – one Fort Leonard Wood building and one Joint Base Lewis McChord building
- Absence of natural gas data – Port Hueneme, three buildings and Naval Station Great Lakes, three buildings)

Electric Results

Overall, the MAPE for electric results was 18.12%, representing average accuracy of 81.88% (n=23) (Table7; Appendix B). Although MAPE of 18.12% is outside of the success criteria described in the performance objectives, stated as +/-10%, it is still considered a "good" forecast according to criteria established by Lewis (1982). Correlations in energy use curves were evident in most buildings.

Natural Gas Results

Natural gas results for the 23 analyzed buildings had a MAPE of 41.80%, or an absolute average accuracy of 58.20% (Table 7). This is outside of the project's stated success criteria of +/- 10% error, but is considered to be within the criteria of a "reasonable" forecast Lewis (1982), as it is within the range of 21-50%. In general, the models appear to be less accurate in predicting actual natural gas usage than electric usage in DoD buildings. This may be due to errors in modeling results, but the natural gas model results align closer with CBECS natural gas values than the metered natural gas values and may point to other sources of error. Natural gas is much more sensitive to heating, ventilation and air conditioning (HVAC) settings and climate than electricity because natural gas in the energy model is only for:

- Hot water (very small amount but very sensitive to user operation)
- Heating (very sensitive to climate and building operation); feedback from personnel indicates that HVAC systems are often operated excessively
- Reheat (very sensitive to HVAC settings and often set up very poorly)
- Infiltration
- Various very large process loads like a pool, cafeteria, or other unique things that are not typically part of REM

These issues can be checked easily in buildings and are good candidates for re-commissioning. Overall, metered values are much higher than modeled values, with the exception of a Leadership in Energy and Environmental Design™ (LEED™) building, and two dorm buildings with questionable occupancy levels.

Energy Use Intensity Results

EUI results had a MAPE of 22.44% (N=23), representing 77.56% absolute average accuracy in EUI predictions (SD=13.48%). This MAPE for the pooled set of buildings is within the stated performance objective criteria of =/- 25% error, and is considered "reasonable" according to established criteria, as it falls between 21%-50% MAPE (Table 7; Appendix B). The highest

energy use, represented by EUI (kBtu/ft²), was found in a cafeteria, dormitories and a gymnasium.

Table 7. Summary data for all analyzed buildings (n=23).

Statistics	Electric	Natural Gas	EUI
Average Accuracy	81.88%	58.20%	77.56%
MAPE	18.12%	41.80%	22.44%

In most cases, there was closer alignment of simulation data to CBECS result, and researchers attribute the deviation between the model and meter data to buildings that are performing worse than should be expected based on their attributes. To further explore the results, analyses were clustered by building use type and plotted against benchmarking results from the CBECS 2003 survey. Examination of this range of buildings improved the findings of the demonstration by allowing visibility of trends within use categories. The various building types included 13 offices, five barracks, five special use buildings (fire station, gym, school, auto facility, and cafeteria).

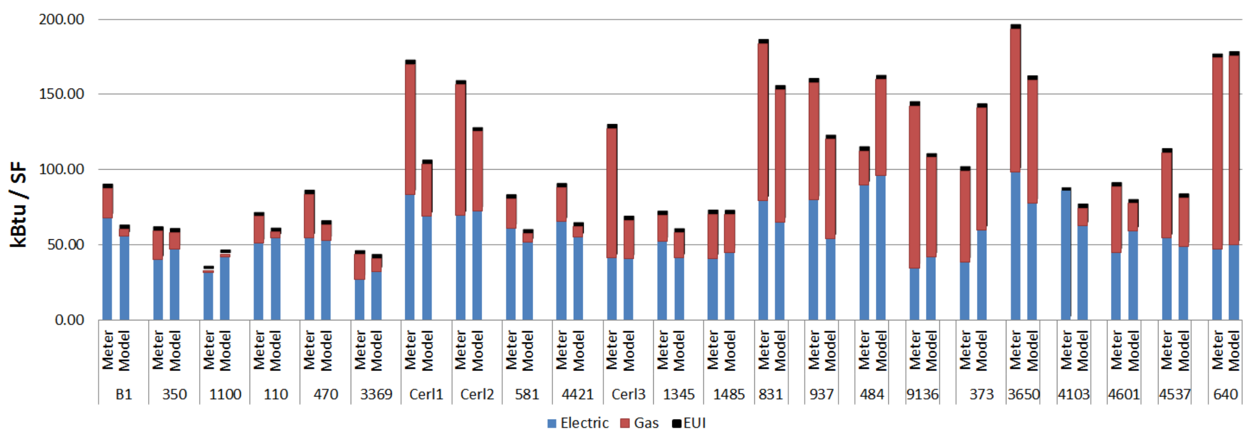


Figure 4. Comparison of meter and model data in relative kBtu/ft².

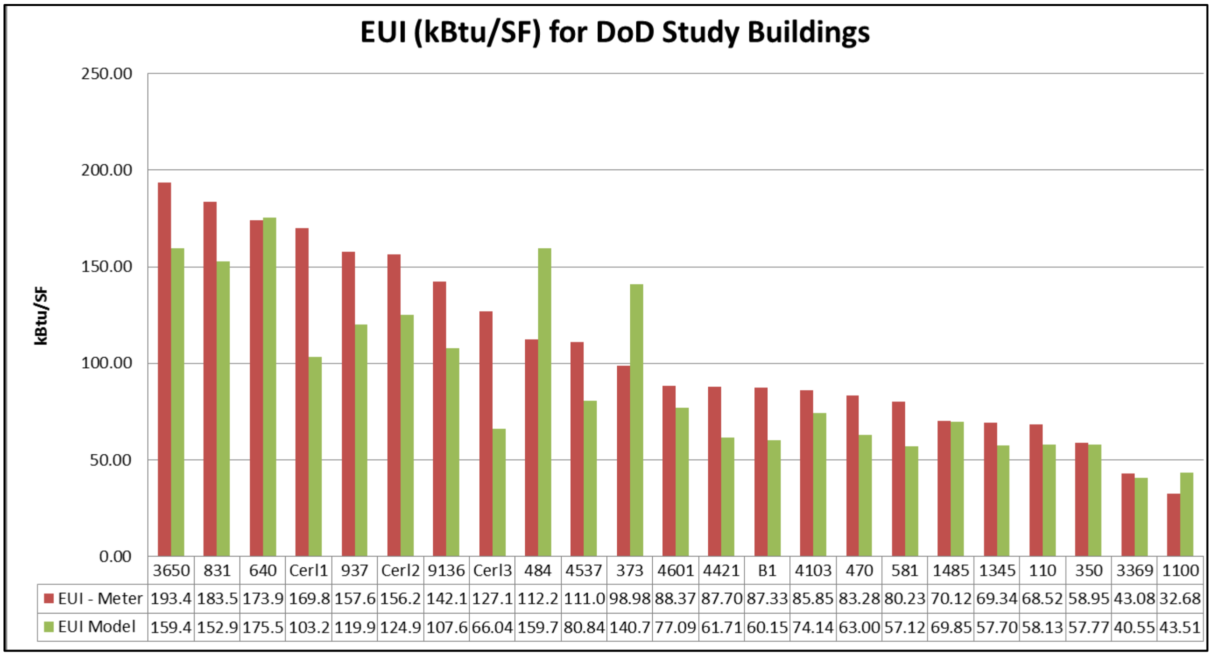


Figure 5. Comparison of meter and model data in relative kBtu/ft².

6.1.1 Offices Subset

In total, 13 offices across seven Army, Navy and Air Force locations participated in the core analysis in the study. The offices ranged in size from 4,800 gross square foot (GSF) to 281,732 GSF (Appendix B). For photos of buildings, please refer to the ESTCP Final Report.

Overall, the offices averaged 85.70% in accuracy when comparing modeled estimates for electric data to electric meter data, representing average MAPE of 14.30%, which is considered a good forecast based on criteria proposed by Lewis (1982). While electric modeling results for offices aligned closely with actual metered usage, natural gas models for offices were on average only 49.48% accurate, with a MAPE of 50.52%, which is considered a reasonable forecast, but is on the cusp of being considered inaccurate (MAPE >51%).

Energy surveys were revisited to investigate buildings where modeled estimates were more than 20% different than meter data. For the office electric data, only Naval building 1100 in Port Hueneme (33.83% error) and Office Building 1345 at Peterson (-21.33% error) were outside of this threshold (see the ESTCP Final Report for discussion of these buildings). Only three buildings were >80% accurate for natural gas estimates and those included Port Hueneme 1100 and the two smallest buildings, 1345 and 1485 at Peterson AFB (Figure 6). The office buildings demonstrated correlation in trend profile shape, but had significant amplitude differences, with the building consuming more natural gas than predicted by the model (Appendix C).

In all cases, with the exception of Building 1100, building natural gas meter and EUI data is higher than what is predicted in the models. While the possibility exists that differences could be attributed to natural gas use related calculations in the models, it should be noted that in general, building natural gas usage and EUI were also significantly higher than CBECS values.

Researchers attribute the deviation between the model, meter, and CBECS results to buildings that are performing worse than should be expected based on their location and attributes.

Overall, modeled and metered electric results aligned relatively well with CBECS 2003 benchmarking results for office building (see Table 10 and Figure 23 in the ESTCP Final Report). MAPE for electric meter data compared to CBECS was 30.13% (69.87% average accuracy). Natural gas meter data deviated greatly from CBECS with MAPE of 122.44% (-22.44% accuracy), while model data was closer aligned to CBECS with MAPE = 42.05% (57.95% accuracy).

The REM workflow seems reasonably accurate for estimating overall EUI for DoD office buildings. Overall, of 13 offices sampled, the MAPE was 22.66%, or an average of 77.34% accurate. Three office buildings (350, 3369 and 1485) were within 90% accuracy and an additional three (110, CERL 2, and 1345) were within 80% accuracy. With the exception of Building 1100 in Port Hueneme, all other office buildings had EUI meter data that was higher than predicted EUI for each building.

Conclusion

Overall, the REM workflow appears to be a good method for predicting electric usage and a reasonable method for EUI predictions for DoD office buildings when looking at MAPEs for the pooled set of office buildings. The high variability in natural gas results for individual buildings and overall MAPE for the pooled set of office buildings needs further investigation. DoD office buildings are consuming significantly more natural gas and have higher EUI values than predicted by the models and compared to similar buildings in the CBECS database.

Energy use curves and trend profiles provide insight on seasonal variations, deviations and correlations for the buildings. Deviations are likely attributed to faulty meter readings, weather anomalies, or operational and mechanical issues at the individual building level. Next steps should include working with individual building managers to investigate operations, system configurations and settings and to attempt to elucidate understanding around spikes in usage or other anomalies in the meter data. In some cases, there may be issues with the meter data itself and there is also a possibility that the meter data was submitted for a weather year that was atypical.

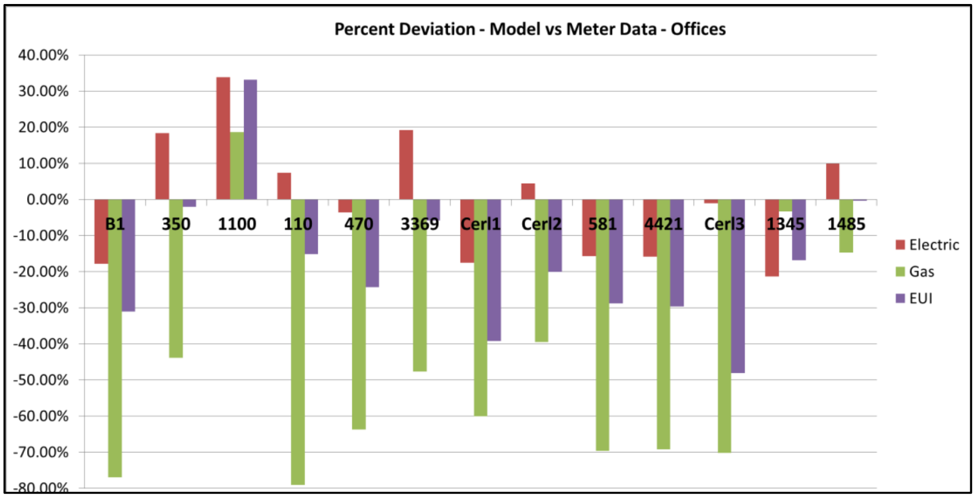


Figure 6. Percent deviation - model vs. metered electric, natural gas and EUI for offices.

6.1.2 Barracks Subset

Of the 23 buildings analyzed, five were dormitories ranging in size from 25,349 GSF to 96,130 GSF. There were an additional four dormitories sampled that were not included in core analysis due to questionable meter data. For photos of buildings, please refer to the ESTCP Final Report.

Overall, dormitory electric estimates were on average 73.25% accurate when compared to meter data (MAPE = 26.75%). While this is outside of the +/- 10% success criteria established in performance objectives, it is considered a reasonable forecast according to Lewis (1982) (Table 6). Modeled natural gas predictions averaged 56.66% accuracy, including an outlier of 179% error at Panama City Building 484, where the model predicted much higher gas usage than was evident when examining meter data. With this outlier removed, natural gas accuracy averaged 73.93% with a MAPE of 26.07% (Appendix B).

When all five barracks were aggregated, energy model predictions were on average 70.12% accurate with a MAPE of 29.88% for EUI predictions. The highest accuracy was with barracks 831, 937, and 9136, which were all >78% accurate. Dorms 484 and 373 were assumed to be 100% occupied throughout the year, and this is not a reasonable assumption for these particular buildings upon reviewing the meter data. Similarly, barracks that were excluded from analysis also had occupancy concerns that were even more dramatic.

Comparisons of barracks buildings to CBECS data is summarized in Figure 30 in the ESTCP Final Report. CBECS data for dorms was not useful for comparisons due the small sample of dorms in the 2003 CBECS survey. As a result, CBECS values are based on larger criteria of “lodging” within each climate zone in order to have sample sizes >10 for CBECS values. Additionally, since the 2003 survey, we have seen an explosion in the use of personal devices such as laptops and tablets, associated increases in plug loads would not have been observed in 2003.

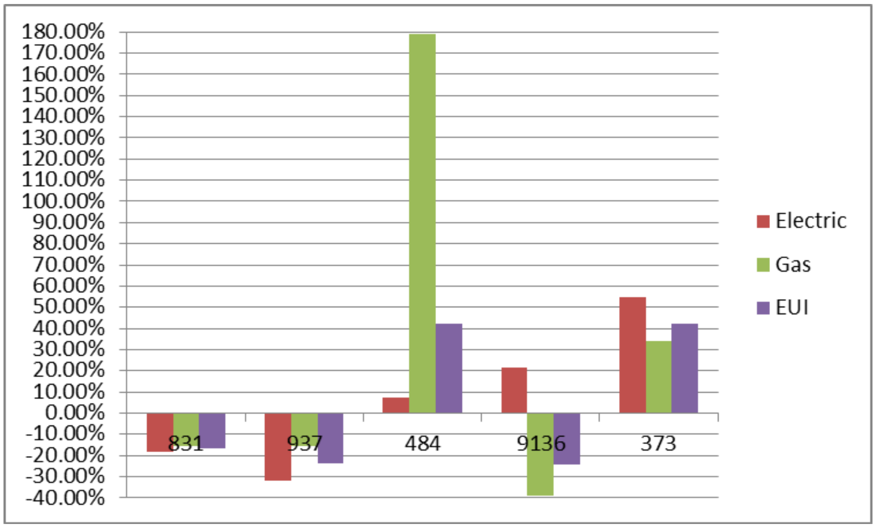


Figure 7. Percent deviation - model vs. metered electric, natural gas and EUI for barracks.

Conclusion

The REM workflow is a reasonable approach to predicting electric, natural gas and EUI in barracks buildings that have consistent occupancy throughout the year. Variable occupancy can skew the data significantly.

If barracks buildings are going to be utilized in REM workflows, users should understand that the energy models assume 100% occupancy. Reduced occupancy levels can be varied in GBS (i.e., 75% occupancy, 50% occupancy); however seasonality of reduced occupancy cannot be accounted for in the building energy model. Given the highly variable nature of DoD barracks and lack of available information on occupancy levels through the year, the REM workflow for barracks may not be ideal, unless users are comfortable with the assumptions described above.

6.1.3 Specialty Use Buildings Subset

In addition to offices and barracks, researchers sampled five specialty use buildings including a dining cafeteria, school, fire station, automotive facility, and a gym. All buildings were under 45,000 GSF and were located at Seymour AFB, with the exception of one gym in Fort Leonard Wood, MO. For photos of buildings, please refer to the ESTCP Final Report.

Overall, energy models for these aggregate specialty use buildings were an average of 80.58% accurate for electricity estimates, with a MAPE of 15.72%, indicative of a good forecast. Energy models were an average of 70.80% accurate for natural gas predictions, with a MAPE of 29.20%, indicating a reasonable forecast. Overall, specialty use building energy models were an average of 85.58% accurate for predicting EUI with a MAPE of 14.42%, signifying a good forecast.

The REM workflow was a good methodology for forecasting electric and EUI for specialty use buildings based on MAPE values between 11-20%. Further, there were close correlations in trend profiles in monthly data charts. The workflow was reasonable at predicting natural gas

usage in specialty use buildings as indicated by MAPE value of 29.2%. Given the specialized building types in this subset, and the limited number of building types in the CBECS database, comparison to CBECS is likely unreliable for these buildings.

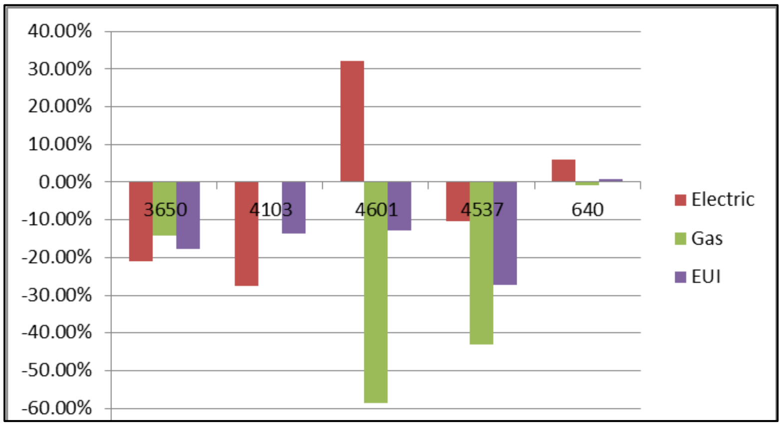


Figure 8. Percent Deviation - model vs. metered electric, natural gas and EUI for specialty use buildings.

6.2 VARIANCE IN MONTHLY CONSUMPTION (BILLING HISTORY)

The calibrated simulation approach in this study involves use of the GBS program and DOE 2.2 engine to model energy use of existing buildings in pre-retrofit conditions and then checked against actual measured values. Researchers compared monthly utility costs between the simulated energy values and actual (metered) energy values using utility rates provided by installation POCs. Utility rates and usage were used as a proxy for utility bills, with the assumption that tariffs are included in the rates provided. Researchers calculated the CVRMSE for each building. Additionally, for comparison, CVRMSE was calculated using energy consumption as opposed to energy costs.

Buildings were not modeled again, refined or recalibrated to get within 15% of CVRMSE, rather the data is presented as a picture of how baseline models performed relative to measured values and can allow identification of which buildings are closest to acceptable calibration thresholds guided by under the ASHRAE Guideline 14-2002.

Three building models were within 15% of CVRMSE for billing, including Building 1 at Peterson AFB, Building 470 at Fort Leonard Wood, and CERL Building 2. Two additional buildings were within 20% CVRMSE for billing data, including Peterson AFB Building 350 (18.73% CVRMSE) and Building 4601 at Seymour AFB (18.84% CVRMSE). Only one building, 4103 at Seymour AFB was within 20% CVRMSE for energy usage. The five buildings within 20% CVRMSE for billing were used to explore ECMs through Design Alternatives in GBS.

6.3 TESTING THE REM PROCESS FOR DESIGN ALTERNATIVES TO MODEL POTENTIAL ENERGY SAVINGS

A subset of five buildings was selected based upon falling within 20% CVRMSE for monthly utility costs and design alternatives for energy conservation were explored for these buildings. PES analyses tables and charts automatically generated in GBS guided researchers in assessing ECMs.

How Potential Energy Savings Analysis Works (see example in Figure 9)

1. GBS receives model, which contains any specific building feature design options defined in Revit or Vasari;
2. For any building features that were not specified, GBS inserts appropriate default values for the building type and location and runs an energy analysis;
3. GBS then generates 50 alternative design variations in the cloud with multiple options for 14 building parameters;
4. GBS then spawns 50 servers and runs all of these alternative models at the same time; and
5. The results of the 51 simulations are displayed in the PES chart with the center line reflecting the initial baseline run.

Estimated Savings from ECMs is expressed as:

- *Metered savings = Metered baseline (kWh, therms, kBtu, cost)–ECMpost (kWh, therms, kBtu, cost)*
- *Modeled savings =Modeled baserun (kWh, therms, kBtu, cost)–ECMpost (kWh, therms, kBtu, cost)*

6.3.1 Design Alternatives - CERL Building 2

For CERL Building 2, an office in Champaign, Illinois, there was a CVRMSE value of 12.6%. PES analyses indicated that the highest energy savings could be gained by modifying wall construction, HVAC type, and plug load and lighting efficiency (Figure 9).

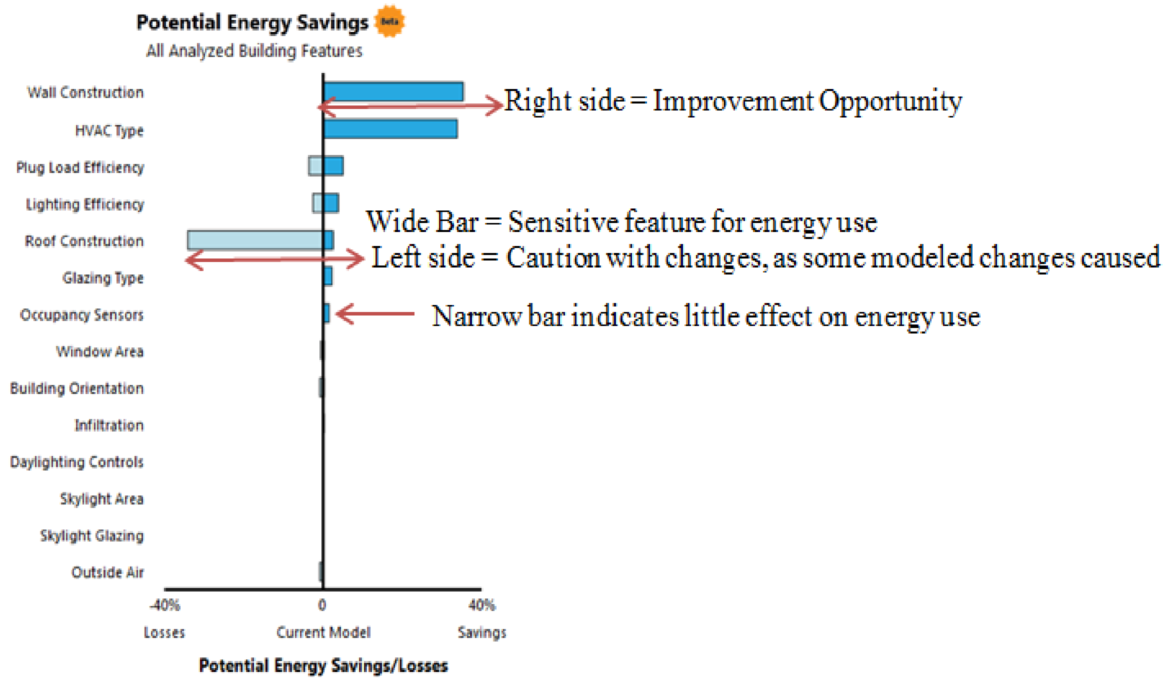


Figure 9. PES chart for CERL Building 2.

A basic package set of measures explored upgrading the HVAC system while utilizing the infrastructure of the existing four pipe fan coil system, reducing lighting power density (LPD) and equipment power density (EPD) by 10% and installing occupancy sensors and daylighting controls. An advanced package included all measures in the basic package, and also included addition of insulation to the massive brick walls, which was the number one recommended improvement but also potentially the most costly.

The basic package set of measures yielded energy savings of 27.02% and $20,723 cost savings compared to metered energy usage, and 8.75% compared to modeled usage and $9,636 in costs savings compared to the modeled baserun. Adding wall insulation under the Advanced Package yielded an additional 26% energy savings (53.25% total savings) and an additional $19,080 ($39,803 total) in annual cost savings compared to the metered baseline. Differences seen between modeled and metered savings are due to energy usage differences between the runs, even though they fall within 15% CVRMSE calibration criteria.

Peterson B1, an office in Colorado Springs, Colorado, had a CVRMSE of 10.39%. A basic package guided by PES Results (Figure 10), explored measures including reducing LPD and EPD by 10% each and adding occupancy and daylighting sensors and controls.

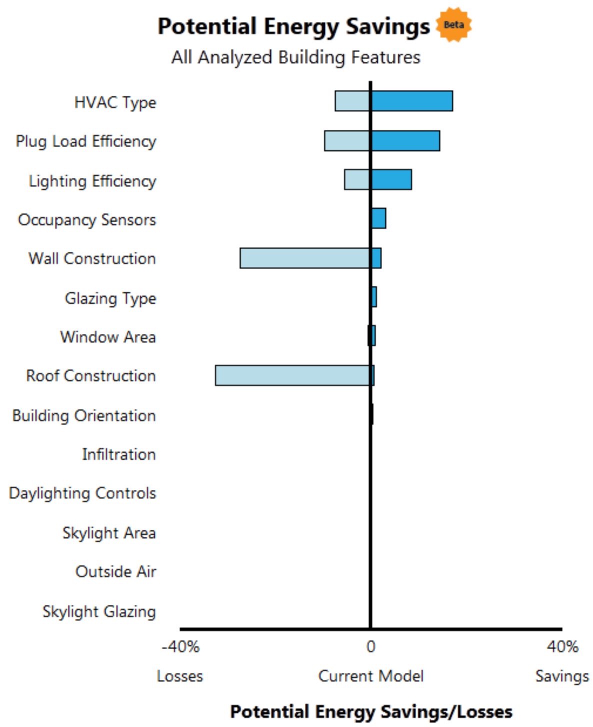


Figure 10. PES chart for Building 1 – Peterson AFB.

There were no high priority envelope measures indicated by the PES Chart, thus an advanced package explored basic package measures and also included a HVAC change to premium efficiency Variable Air Volume (VAV) with reheat.

Lighting, equipment and control improvements yielded a 40% improvement in EUI over metered baseline values, and a 12.81 % improvement over EUI from the modeled baserun. Annual cost savings were $105,000 from the metered baseline, and $17,727 from the modeled baserun. This discrepancy is linked to differences between metered and modeled energy estimates, despite CVRMSE values within 15%. With HVAC improvements added to the improvements identified, facility owners may realize an additional $28,828 in annual cost savings ($134,463 total) and 1.95% improvement in EUI (41.95% total) over metered values.

Office building number 470 at Fort Leonard Wood, Missouri, had a CVRMSE value of 14.47% between simulated and metered monthly cost data. PES analyses indicated that greatest savings may be gained from upgrading HVAC, upgrading glazing, altering window area and improving plug load efficiency and lighting efficiency (Figure 11).

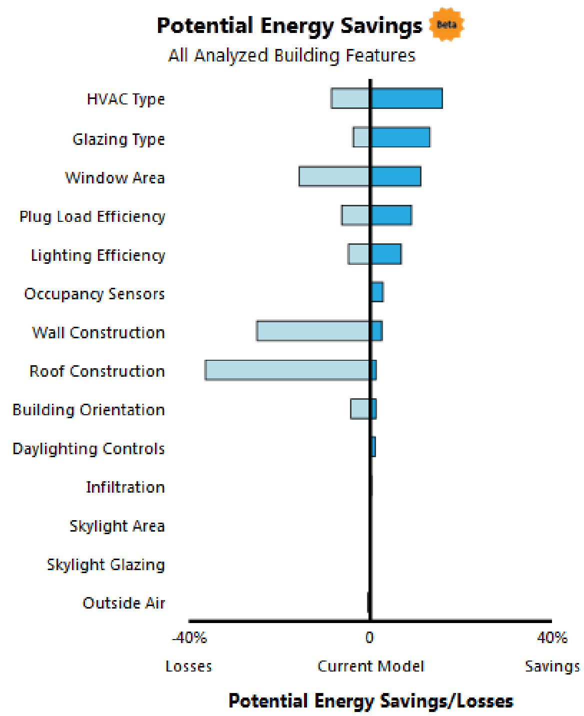


Figure 11. PES Chart for Building 470-Fort Leonard Wood.

It was determined that changing window area was impractical and that was removed from consideration. Researchers thus investigated a basic package that included 10% improvement to equipment and lighting efficiency, daylighting and occupancy controls and HVAC equipment improvements. Researchers selected an 11.3 EER packaged VAV system, which offers a slight improvement in efficiency over the current system, but does not require an overhaul of the existing HVAC infrastructure. Existing windows are double-pane, thus upgrades to these windows were considered as an Advanced Package item. Given that two identified improvements, HVAC and window glazing have been upgraded in the building relatively recently, these were assessed iteratively in addition to basic package measures as moderate and advanced packages.

Exploration of design alternatives indicated that the basic package of ECMs, including lighting efficiency, equipment efficiency and control improvements yielded a 31.79% improvement in EUI and cost of $73,067 over metered baseline values, a 9.7 % improvement in EUI and $13,763 in savings from the modeled baserun. Adding HVAC improvements decreased EUI by an additional 6.24% and resulted in an additional $9,506 in cost savings ($82,573 total) above the metered baseline basic package reductions. The combination of HVAC improvements and window upgrades beyond the basic measures yielded a total 45.84% improvement in EUI and an estimated total annual cost savings of $90,420.

Office building 350 at Peterson AFB had a CVRMSE value of 18.37%. The PES chart (Figure 12) reveal that the biggest savings can come from alterations to glazing type, plug load efficiency, window area, lighting efficiency and HVAC type.

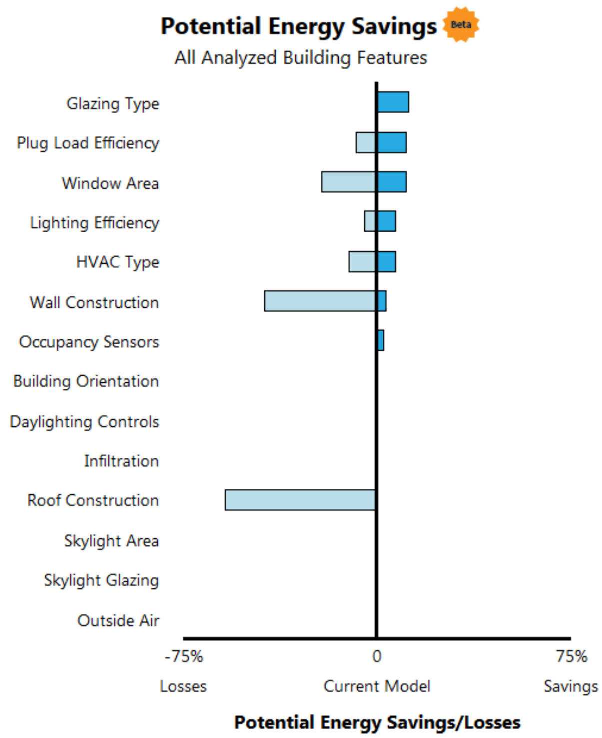


Figure 12. PES chart for Building 350 - Peterson AFB.

It was determined that changes to window area are not feasible and that existing windows are double pane and tinted, although not the latest in window design. Therefore researchers explored a basic package of measures that investigated reduction in plug load and LPD by 10% each plus the addition of occupancy sensors. The PES analysis indicated that HVAC upgrades presented low opportunity for energy savings, particularly since it would involve under floor air distribution and significant modifications to the existing infrastructure. HVAC upgrades were therefore not explored for this building.

Exploration of basic measures within GBS Design Alternatives revealed that improving LPD by 10 % and EPD by 10% plus adding occupancy sensors is estimated to improve EUI by 3.64%, and reduce energy costs by $7,906 annually compared to metered data for the building. Improvements compared to the modeled baserun indicated an improvement of 7.49% for EUI, and annual cost savings of $18,666.

Building 4601, a fire station at Seymour AFB, North Carolina, had a CVRMSE value of 18.84%. The PES chart indicated that the highest energy savings could come from upgrades to HVAC type, wall construction, glazing type, LPD, EPD, and window area (Figure 13). The HVAC system that indicated improvement was an under floor air distribution system, which was not considered feasible for this building.

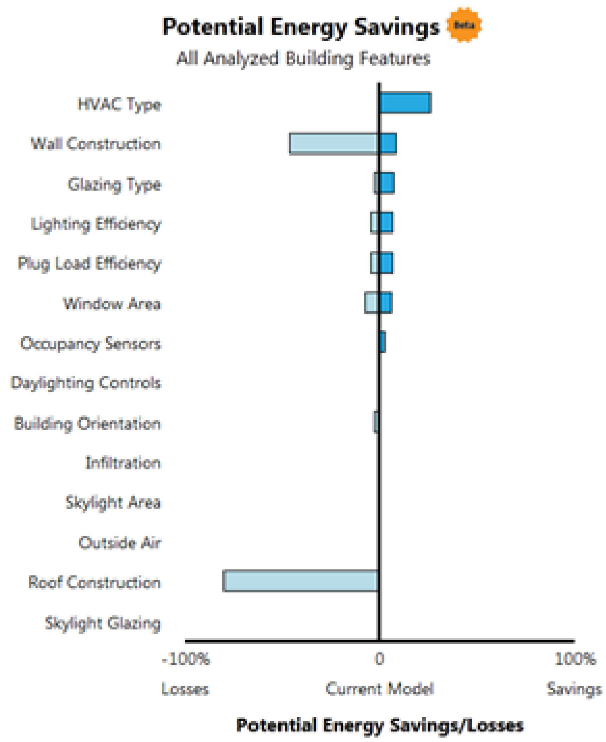


Figure 13. PES chart for Building 4601 - Seymour AFB.

A basic package of measures explored 10% improvement to lighting efficiency (LPD 10% less than base run), 10% improvement to equipment efficiency (EPD 10% less than base run), and the addition of occupancy sensors (though they showed only marginal savings on the PES chart). Window glazing could be improved from dual pane (baseline) to reflective, insulated, low E windows in a design alternative (Figure 13). Exploration of basic measures within GBS Design Alternatives helped improve EUI by 8.40% against the modeled baserun and 20.11% compared to the metered baseline. Advanced package upgrades yielded a modeled savings of 14.88% and 25.77% against the metered baseline.

6.4 TIME AND COST TO ENERGY MODEL

While constructing BIM models, researchers documented the time required for model creation and energy analysis and compared time required for each workflow. These time-based tests were completed after a significant period of testing and workflow refinement. The Revit-based workflow required an average of 27.54 minutes (SD=6.75). This included time required for creation of FormIt mass models in the field, model enhancements in Revit, and energy analysis in Revit. The Vasari based workflow required an average of 17.81 minutes (SD=5.87), including integrated energy analysis natively in Vasari. Buildings that required more time were often more complex in shape, with open courtyards or drill decks, such as dormitory building 484 in Panama City, FL.

Given the data above, it can be reasonably assumed that conceptual energy models and analysis can be executed in 1 hour or less in most cases. It should be noted that this assumes that no travel is required, and does not include time required for installation personnel to answer questions regarding building construction and operations (the average time required for this aspect is 2

hours unless assumptions are derived from satellite photos and building knowledge instead of building documentation).

Existing methods employed by the DoD to measure energy consumption and building performance has historically been limited to benchmarking or energy audits. While benchmarking methods (such as Energy Star® Portfolio Manager or CBECS) are quick, they do not identify specific opportunities for energy-saving occasions in buildings and are often imprecise because they are not customized to the building and are thus prone to significant error. They too are subject to the problems with access to and availability of quality data. Traditional energy audits might be more accurate and customized than benchmarking, but are labor intensive, expensive, time-consuming, and require a high level of expertise; therefore, they are not scalable across the DoD portfolio.

Three levels of energy audits are typically used: walkthrough (ASHRAE Level 1), general (ASHRAE Level 2), and investment grade (ASHRAE Level 3). Requirements for each of these levels can often lack detail and it is generally acknowledged that the levels do not have distinct boundaries (Shapiro, 2009). Researchers investigated whether Rapid Energy would allow buildings to be evaluated within a shorter time and smaller budget than audits. While REM processes include the many of the benefits of Levels 1-3 energy audits, the workflow does not provide a direct match to one particular audit type, but is a closer match to the outputs of an ASHRAE Level 2 audit, with added benefits of computer simulation of a Level 3 audit. Results are summarized in section 7.3

Researchers are not recommending replacement of ASHRAE audits for DoD facilities. However given the time, expense, and expertise required for ASHRAE audits, REM approaches can be used at early stages of energy analysis to determine buildings that are: poorly performing, the best candidates for retrofits, and may present the best potential opportunities for energy savings, with the added benefit of computer simulation and modeled comparison of energy conservation measures.

6.5 QUALITATIVE PERFORMANCE OBJECTIVES

Autodesk has recently begun technology transfer associated with the ESTCP Rapid Energy Modeling Demonstration Project. Researchers have assembled a training curriculum that includes a webinar, hands-on demonstration, and free optional enrollment in an advanced certificate program.

Given the diversity of user profiles, goals, availability of building information and time, there are multiple workflows to select from, based on end goals, systems, access and user profiles. Options include tablet-based mobile app FormIt for conceptual modeling with further refinement available in Revit or Vasari. Modeling can also be done in Revit (detailed and conceptual modeling) and Vasari (conceptual modeling), with integrated energy analysis through GBS. Additional refinement of the energy models and exploration of design alternatives can be done through the GBS web service.

As added value, DoD staff who participated in the ESTCP demonstration have been invited to enroll in the Autodesk Building Performance Analysis (BPA) Certificate Program under a group

specifically for DoD installation staff. The personnel who have received training to date have expressed a high degree of satisfaction with results from ESTCP for their installation, the ease and speed of the workflow, and content in reports and GBS dashboards.

There is intrigue around the ability to produce rapid coarse models with acceptable results that will allow staff to do comparative runs and quickly answer questions about which parameter has the most influence on the building, such as the roof, walls, windows, etc. Staff have communicated that REM is a good way to answer questions that are often explored by DoD energy managers when initially contemplating upgrades.

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7.0 COST ASSESSMENT

Cost estimates are organized into high and low range estimates for a given site. The high range estimates assume computer hardware and would be purchased. This assumed hardware purchase is not mandatory as existing installation laptop/desktop computers can be used for the REM solution. The high range estimate also assumes software will be purchased specifically for this task. This may not be necessary as the Air Force, Navy and the U.S.Army Corps of Engineers (USACE) have existing enterprise software licenses for most software titles used for REM. The software titles not covered in the enterprise agreements are available as free software downloads. The low range cost estimates assume the utilization of existing installation hardware and the use of the existing enterprise licensed (or free) software. The operational costs after the up-front expenditures would be $300 per building modeled with this process multiplied by the number of buildings studied at an installation. Our enterprise cost model is assuming one set of REM tools per installation at 185 installations as a full deployment of this technology (Table 8).

7.1 COST MODEL

Table 8. REM cost model.

Cost Elements (Unit One)	Data Tracked During the Demonstration	Estimated Costs for Installation	Unit Measure
Hardware capital costs *(Determined based on existing desktop or laptop hardware)*	Typical laptop/desktop cost during demonstration period	$0-$1,350	Per user
Software costs *(Determined based on access to DoD Enterprise Software Licenses*	Commercial-off-the-shelf (COTS) software fees during project demonstration	$0-$4,590	Per Installation
Software installation costs	Time/labor to install/downloaded software	$200	Per user
Operational costs	Level of effort to model building, add operational attributes and produce energy model and reports	$300	Per building
Software maintenance	Frequency of available software upgrades	$600	Yearly
Operator training	Length of time for training session (1day)	$500	Per user
Upfront set up costs (not including operational costs)		$1300 (low range)-$7240 high range)	

COTS = Commercial-off-the-Shelf

7.2 COST DRIVERS

The hardware costs and the software costs for this project are well known and reasonably predictable. The major costs have been variable costs - of collecting the operational attributes of the buildings, modeling and analyzing buildings and creating ECMs. This may well prove to be the case with a larger population of sites. Some installations have this operational information readily available; at other locations this information is in disparate sources that make collecting the information more challenging and potentially increasing costs. In these cases were this information cannot be obtained cost effectively (or at all), default ASHRAE settings and

program defaults are used to cap data collection costs. An additional cost driver is the number of buildings studied with the REM methodology. This is a linear progression with the per-building REM modeling costs outlined in section 7.1.

Site specific and regional issues may come into play through the interaction of the installation POC with the Information Technology (IT) department at each installation. The installation of new software titles may require IT participation. The process to add new software titles vary per agency and per location. This is a potential cost variable to consider when deploying this technology. DoD Enterprise-wide life cycle costs for REM components are summarized in Table 24 in the ESTCP Final Report.

7.3 COST ANALYSIS AND COMPARISON

REM utilizes recently available digital 3D modeling technologies. The REM approach does not conform precisely to existing energy assessment methods making direct comparisons challenging but in the end productive. In addition, as there is no energy efficiency equipment installed at the installation with this demonstration project, some of the life cycle cost methods are difficult to fit to this project.

A useful approach in forming a life cycle cost understanding of this technology is to compare REM to ASHRAE Energy Audits. While REM and energy audits approach the subject matter from different viewpoints with substantive differences in methodology, there is a significant overlap in the data produced, accomplishing similar asset management objectives and in the overall desired outcomes.

REM Per-Building Operational Costs Compared to ASHRAE Audits

Reported costs for detailed energy audits may vary from \$0.12 up to \$0.503 per square foot, depending on the size and complexity of the building (Baechler et al., 2011). For the purposes of this study, researchers used the low-range estimate. In this study of 23 buildings, a total of 1,497,275 ft² of conditioned space was modeled. This yields a low end cost of \$179,673 using the value of \$0.12 per ft² to conduct a Level 2 audit on the population of the studied REM buildings. In comparison, applying the REM process to this population of buildings yielded \$0.005 per ft² for a total cost of \$6,900 to conduct the REM process on the total population of 23 buildings. This represents a cost savings of 96.17%.

With an assumed time requirement of 3 hours per building (include survey collection, modeling, and energy analysis), REM provides an opportunity for time savings (87.5% low end, 96.25% high end) compared to Level 2 auditing approaches that may require 3-10 days.

From this demonstration project, the REM process has shown to be useful to in making energy management decisions. The REM process can be accomplished with personnel with less exacting expertise in energy systems, saving personnel cost and increasing the ability to scale. With the number of individuals doing energy assessments, the number of buildings studied can also increase. These characteristics of REM allow this process to be more cost effective then conducting typical Level 2 audits.

REM may also precede the standard energy audit process to act as a triage with justifiable recommendations to select the high priority buildings for more detailed study. With the ability to compare the relative merits of a variety of ECMs, the REM process can act as a quick proxy for informing installations where to concentrate building life cycle cost (BLCC) studies and follow-on detailed actions.

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8.0 IMPLEMENTATION ISSUES

To facilitate the future deployment of this technology the following topics should be considered.

8.1 METER DATA COMPARISONS

There were several issues related to the implementation of the project, specifically comparison of model estimates to meter data. These are germane in the execution of this demonstration pilot as a blind study, but may be less significant in future deployments of this technology because often the meter data does not exist or is unusable, and the technical confidence for this approach has been demonstrated by this project.

The results of this project recommend REM as a method to improve DoD building data availability considering the difficulty with the current building energy meter deployments at the DoD. REM also helped identify meters that were not functioning correctly, or were not scaled correctly. Meter data does not impact the recommendations of ECM directly, as ECM recommendations are not based on the availability of meter data. If meter data is available, it increases the transparency of the energy performance of a building and can supplement the ECM decision process in support of the REM ECM recommendations.

There are numerous concerns with the quality of meter data at DoD buildings, including common issues of zero readings, time gaps, negative readings, large jumps or jumps in usage, and unknown or incorrect scaling of meters. There were also other issues where facility personnel were unaware of how meters were divided amongst building(s), how to access interval data, how to identify or correct meter scaling, and instances where staff inaccurately designated units, or the meter data was not trusted by staff familiar with the building (see Appendix D in the ESTCP Final Report for summary of meter data issues with individual buildings).

These numerous issues draw attention to the need for DoD to review data from existing meters for anomalies, and for additional and perhaps periodic personnel training as the Advanced Metering Initiative (AMI) continues throughout DoD installations. Future research using the existing data set should compare current results to meter data after smoothing or removing outlier data.

8.2 SITE SELECTION AND DATA GATHERING

In general, installation personnel seem stressed, and found it difficult to take time to obtain metering data and answer building-related questions.

Several installations known to have individually metered buildings chose not to participate in REM project due to lack of manpower or previous commitments. The government sequester that was in effect during the study period may have added to these resource and bandwidth issues.

Surveys to installation POCs contained numerous energy-related questions that were used to help researchers interpret results, but are not necessary data inputs for the REM workflows. In some cases, suspected misinformation was provided in the survey responses.

Data requirements for the model can be streamlined to the following minimum data requirements.

- Location and confirmation that building is visible via Google satellite,
- Building year of construction and major renovation,
- Building use type,
- Operating schedule,
- Gross floor area,
- Building height (whether or not height includes unconditioned attic space or open air, conditioned spaces?),
- HVAC system type or selection of best fit from Vasari or GBS selection options,
- Number of floors (can be estimated from satellite, if unavailable),
- Floor to floor height (can be estimated from satellite, if unavailable),
- Percentage window glazing (can be estimated from satellite/aerial images, if unavailable),
- Percentage skylight glazing (can be estimated from satellite, if unavailable),
- Exterior wall construction and insulation levels (can be estimated from satellite/aerial images and year of construction/renovation, if unavailable),
- Roof construction and insulation levels (can be estimated from satellite and year of construction/renovation, if unavailable),
- Glazing type and skylight types: single pane, dual pane, triple pane; tinted, low-e (can be estimated based on year of construction/renovation and location if unknown), and
- Documentation of known structural or operational idiosyncrasies.

When some model inputs are unknown, assumptions can be made based on year of construction and/or retrofit and satellite images from Google or Bing. If a user wants to minimize assumptions about a building, they either need knowledge of the building or access to construction documents. Construction documents would also provide the most accurate information on building floor area. The use of as-built documentation was initially explored as a method for data capture; this information can be used to define interior zoning, space use types, mechanical/ electrical system design and building envelope design but given the time required, it is better suited to creation of detailed energy models, not REMS.

While many assumptions can be derived from satellite images and on-site visits are not required for the REM workflows, it is helpful to have knowledge of the building, access to building documentation or access to someone with knowledge of the building to help determine model inputs.

8.3 ANALYTICAL MODELING

The analysis platform and workflow do not allow for capturing unregulated/process loads. Types of spaces with high energy consumption have the potential to throw off results. Examples may include: labs, data centers, or kitchens. And process load types such as exterior lights, elevators, lab equipment, or machine room equipment may also have an effect on end use.

It should also be noted that this REM methodology using the DOE 2.2 engine is not capable of modeling district systems such as steam or chilled water, nor is it capable of modeling multiple HVAC systems, radiant heat, or heat recovery systems. Sensitivity in the models is derived from limitations in modeling or understanding of the spaces such as attics, basements, atriums, unconditioned spaces, and double height spaces. There may also be impact from exterior obstructions such as overhangs, adjacent buildings and solar shading. There may be impact from roof zones fabric gains. Additionally, comprehending the operational schedule is important and useful in understanding seasonal variations or periods of non-use, which happens frequently for DoD dormitories. The building models that most closely followed the building profiles were also the closest in replicating the metered energy use, and it is possible that a better understanding of operating schedules, seasonal variations in usage and of space use diversity, could have improved results.

The recently added PES feature within the REM software (GBS) allows multiple simultaneous energy simulation runs, each varying values for building features. This offers significant benefit in that it automates initial exploration and identification of ECMs, allowing users to quickly see which building parameters have the most influence on energy consumption and the highest opportunity for PES. The current ESTCP project used a beta version of the PES tool, which ran 50 different building simulations. The production version since released utilizes 37 parameters and tests extreme values against the baseline mode in the initial model. This format can provide teams with a high level understanding of PES, building energy performance for each measured parameter, and can provide insight on building sensitivity to various parameters of the buildings performance.

GBS has the capability of analyzing renewable energy potential, including photovoltaic and wind energy, and can also calibrate results to specific weather years for which meter data is available. A government satellite blackout in the fall of 2012 prevented researchers from calibrating energy models to the weather year in GBS and manual calibration using external weather data files was outside of the scope of the project. Future research should explore calibration to actual weather for a specific year and document buildings that would be best for renewable energy implementation based on assumed installation costs, available utility rates, modeled geometry and location.

8.4 FUTURE OF REM

Electric results were consistently higher in accuracy than gas or EUI results and researchers recommend further exploration around gas results. The project’s performance metrics provided insight on accuracy and deviations; however, the correlation of energy use curves and building use categories provide greater insight on accuracy of results and on variations throughout the year. Deviations observed between meter and modeled data can be used to identify buildings that

are not operating as expected and should be prioritized for further investigation and considered for retrofits.

REM has the potential to help DoD scale energy assessments across the building portfolio, determine buildings in the portfolio that present the best opportunity for retrofits, quickly evaluate relative benefits of ECMs through auto-simulation of PES, and contribute to energy and cost savings for the DoD.

The REM workflows allow DoD facility managers and energy managers to quickly create building models based on limited information, rapidly assess buildings that are using the most energy, and generate reports. Additionally, using the PES chart and automatic simulations, staff can quickly see sensitivity of the building to changes in parameters, and the comparative value of modifications to HVAC, roof, walls, windows, lighting, equipment, etc. REM results can also help DoD make informed decisions about which buildings can benefit most from energy retrofits, and may be the most practical to meter and audit. This technology can help DoD to meet existing energy auditing and energy management reporting requirements including EISA 2007.

The REM workflow is easy to learn and DoD facility managers can generally begin creating energy models and interpreting results after 3 hours of instruction. REM workflows can help scale energy analysis throughout the DoD at a pace that is >90% faster and 95% less expensive than ASHRAE audits. Initial cultural indications are that this method is well received at the installations. While the technology is new, this process utilizes a category software tools that are familiar to installation facility asset managers (Google Earth and computer assisted drawing [CAD]/BIM software). The learning curve for this technology is measured in hours, and the startup fees are low. This proves that this technology can be used in production at the installations and move beyond its current prototype status.

Deeper investigations may include applying REM across more climates zones and building types, comparisons of results based on building size and climate zone, or examinations of results when comparing with meter data at intervals versus no interval data. Studies on the potential improved accuracy of REM when using smoothed meter data, as well as tracking the actual energy savings of simulated ECMs to the actual installed energy conservation hardware over time, are all productive areas of future evaluations for this REM technology.

Future technical studies of REM may prove useful, for instance examining connections to operational asset management and real property databases systems such as USACE Builder software, the Military Health Service Defense Medical Logistics Standard Support System (DMLSS) or the Air Force Geo-base system. With these systems, operational, material and geometric attributes of the model may be effectively loaded without operator input, scripting the data-loading phase could scale the process exceptionally. With integration to these systems, the REM process could prove more efficient by working within the context of the daily activities of the installation and would allow for REM analysis on the entire installation at once. This would allow installations to have EISA type reporting information for the entire energy modeled installation inventory each year, as opposed to 25% annually in currently mandates.

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APPENDIX A

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APPENDIX B

SUMMARY DATA- ALL VIABLE BUILDINGS: OFFICES, BARRACKS, SPECIALTY USE, COMBINED

Building Number	Building Type - Modeled	Division	Gross Floor Area- Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error- Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
B1	Office	Air Force	281,732	CO	5,590,418	4,593,182	-17.84%	82.16%	5524	1270.54	-77.00%	23.00%	87.33	60.15	-31.12%	68.88%
350	Office	Air Force	148,801	CO	1,728,137	2,046,233	18.41%	81.59%	2873.363	1611.969	-43.90%	56.10%	58.95	57.77	-2.00%	98.00%
1100	Office	Navy	120,925	CA	1,105,292	1,479,161	33.83%	66.17%	179.1	212.5311	18.67%	81.33%	32.68	43.51	33.14%	66.86%
110	Office	Navy	119,050	FL	1,768,200	1,897,648	7.32%	92.68%	2122.8	443.871	-79.09%	20.91%	68.52	58.13	-15.17%	84.83%
470	Office	Army	101,565	MO	1,621,858	1,564,214	-3.55%	96.45%	2922.467	1060.139	-63.72%	36.28%	83.28	63.00	-24.35%	75.65%
3369	Office	Joint Base	59,578	WA	469,930	560,350	19.24%	80.76%	962.9	503.6395	-47.70%	52.30%	43.08	40.55	-5.87%	94.13%
Cerl1	Office	Army	52,739	IL	1,288,807	1,062,475	-17.56%	82.44%	4560.38	1820.617	-60.08%	39.92%	169.88	103.28	-39.20%	60.80%
Cerl2	Office	Army	48,301	IL	979,952	1,022,858	4.38%	95.62%	4200.35	2543.372	-39.45%	60.55%	156.21	124.93	-20.02%	79.98%
581	Office	Navy	40,287	FL	716,700	604,483	-15.66%	84.34%	786.1	238.2419	-69.69%	30.31%	80.23	57.12	-28.80%	71.20%
4421	Office	Air Force	37,088	NC	706,325	594,687	-15.81%	84.19%	842	259.2037	-69.22%	30.78%	87.70	61.71	-29.63%	70.37%
Cerl3	Office	Army	23,639	IL	282,577	279,563	-1.07%	98.93%	2040.17	606.9196	-70.25%	29.75%	127.10	66.04	-48.04%	51.96%
1345	Office - Bank	Air Force	7,772	CO	118,197	92,989	-21.33%	78.67%	135.53	131.0553	-3.30%	96.70%	69.34	57.70	-16.79%	83.21%
1485	Office - Bank	Air Force	4,834	CO	57,680	63,413	9.94%	90.06%	142.1	121.2382	-14.68%	85.32%	70.12	69.85	-0.38%	99.62%
Summary Data for Offices							Average Accuracy	85.70%			Average Accuracy	49.48%			Average Accuracy	77.34%
							Mean Absolute Percentage Error (MAPE)	14.30%			MAPE	50.52%			MAPE	22.66%
							STDEV	8.93%			STDEV	25.15%			STDEV	14.41%
							CoV	10.41			CoV	50.84			CoV	18.63
							MFE	2.01			MFE	18.81			MFE	21
							MAD	7.21			MAD	18.85			MAD	22
							MSE	70.28			MSE	684.38			MSE	913.06

APPENDIX B (continued)

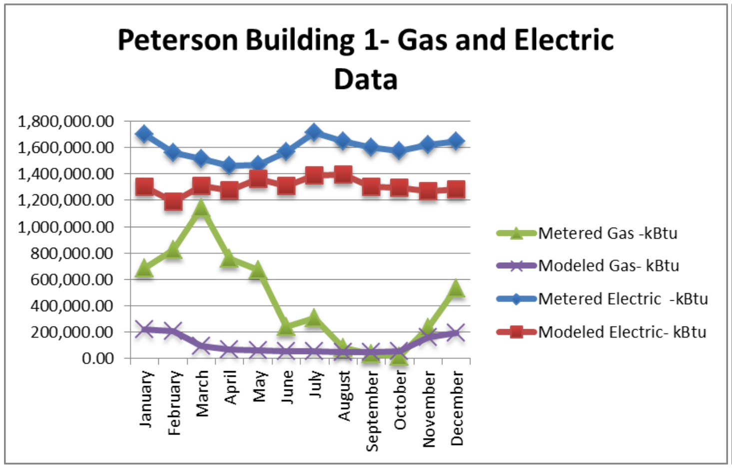
SUMMARY DATA- ALL VIABLE BUILDINGS: OFFICES, BARRACKS, SPECIALTY USE, COMBINED

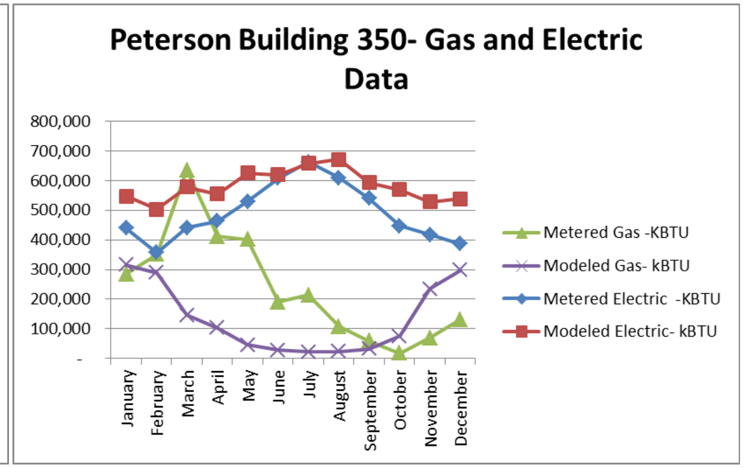
Building Number	Building Type - Modeled	Division	Gross Floor Area- Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error-Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
831	Barracks	Army	40,840	MO	948,960	777,496	-18.07%	81.93%	4257.628	3593.201	-15.61%	84.39%	183.56	152.96	-16.67%	83.33%
937	Barracks	Army	55,724	MO	1,296,922	880,220	-32.13%	67.87%	4359.926	3680.78	-15.58%	84.42%	157.68	119.97	-23.92%	76.08%
484	Barracks	Navy	96,130	FL	2,513,700	2,693,241	7.14%	92.86%	2208.8	6162.982	~~179.02%~~	~~-79.02%~~	112.22	159.73	42.33%	57.67%
9136	Barracks	Joint Base	25,349	WA	255,349	310,415	21.56%	78.44%	2732.8	1669.32	-38.92%	61.08%	142.19	107.65	-24.29%	75.71%
373	Barracks	Navy	76,282	ME	858,400	1,329,284	54.86%	45.14%	4,621	6200.039	34.17%	65.83%	98.98	140.75	42.20%	57.80%
Summary Data for Barracks							Avg Accuracy	73.25%			Average w. outlier removed	73.93%			Avg Accuracy	70.12%
							MAPE	26.75%			MAPE	26.07%			MAPE	29.88%
							STDEV	18.07%			STDEV	12.25%			STDEV	11.71%
							CoV	24.67			CoV	189.12			CoV	16.69
							MFE	0.999			MFE	12.43			MFE	2.71
							MAD	14.94			MAD	22.78			MAD	38.42
							MSE	279.24			MSE	650.45			MSE	1510.58
3650	Cafeteria	Air Force	28,013	NC	805,718	636,028	-21.06%	78.94%	2669.9	2294.736	-14.05%	85.95%	193.47	159.41	-17.61%	82.39%
4103	School	Air Force	25,851	NC	650,258	470,667	-27.62%	72.38%	0	310.1262			85.85	74.14	-13.64%	86.36%
4601	Firestation	Air Force	43,187	NC	564,493	746,343	32.21%	67.79%	1,890	781.9529	-58.63%	41.37%	88.37	77.09	-12.77%	87.23%
4537	Automotive Facility	Air Force	38,700	NC	613,119	549,983	-10.30%	89.70%	2,203	1251.493	-43.19%	56.81%	111.00	80.84	-27.17%	72.83%
640	Gym	Army	20,889	MO	287,682	304,660	5.90%	94.10%	2652.367	2627.316	-0.94%	99.06%	173.98	175.55	0.91%	99.09%
Summary Data for Speciality Use Buildings							Avg Accuracy	80.58%			Avg Accuracy	70.80%			Avg Accuracy	85.58%
							MAPE	19.42%			MAPE	29.20%			MAPE	14.42%
							STDEV	11.18%			STDEV	26.39%			STDEV	9.47%
							CoV	13.87			CoV	37.28			CoV	11.06
							MFE	6.56			MFE	10.57			MFE	17.13
							MAD	13.42			MAD	15.37			MAD	17.76
							Electric				Gas				EUI	
Summary Data for All Analyzed Buildings							Avg Accuracy	81.88%			Avg Accuracy	58.20%			Avg Accuracy	77.56%
							MAPE	18.12%			MAPE	41.80%			MAPE	22.44%
							STDEV	12.31%			STDEV	24.05%			STDEV	13.48%
							CoV	15.03			CoV	43.38			CoV	17.38
							MFE	2.78			MFE	13.30			MFE	16.08
							MAD	10.24			MAD	19.75			MAD	24.92
							MSE	154.12			MSE	671.74			MSE	989.07

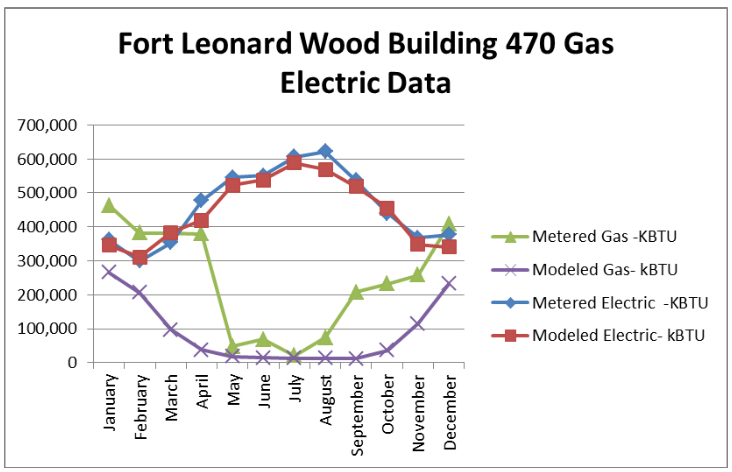
APPENDIX C

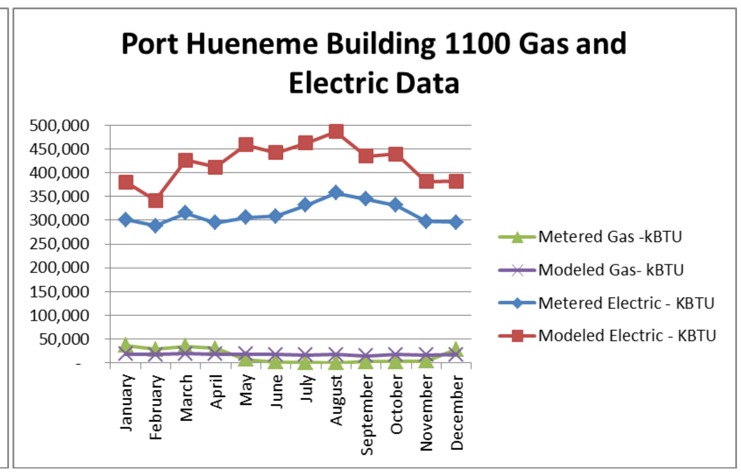
MONTHLY GAS AND ELECTRIC CHARTS

Offices:





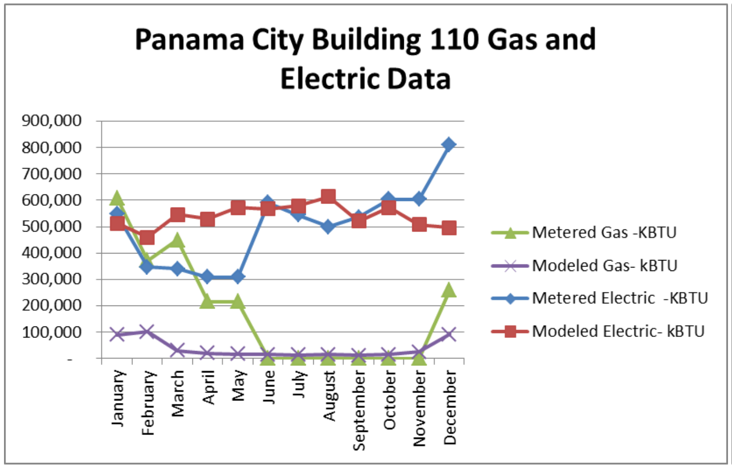


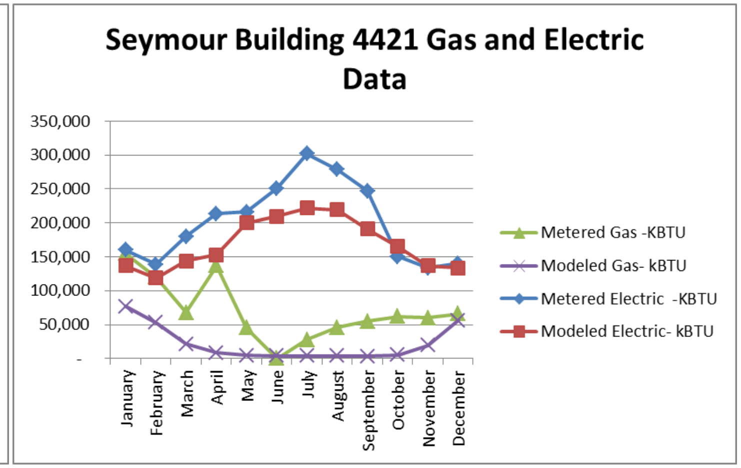


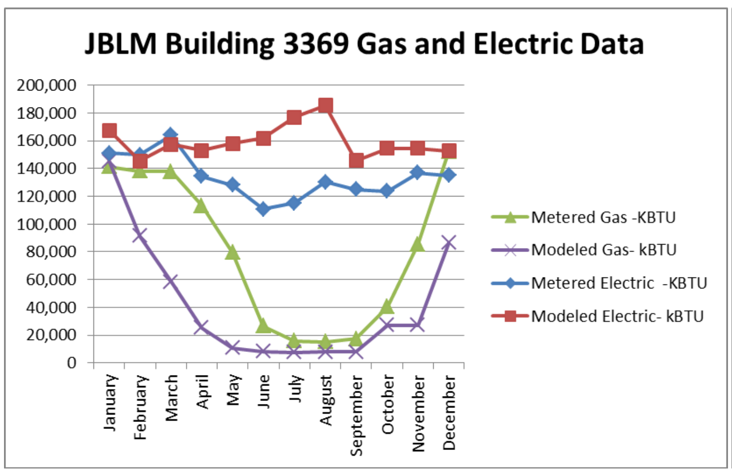
APPENDIX C (continued)

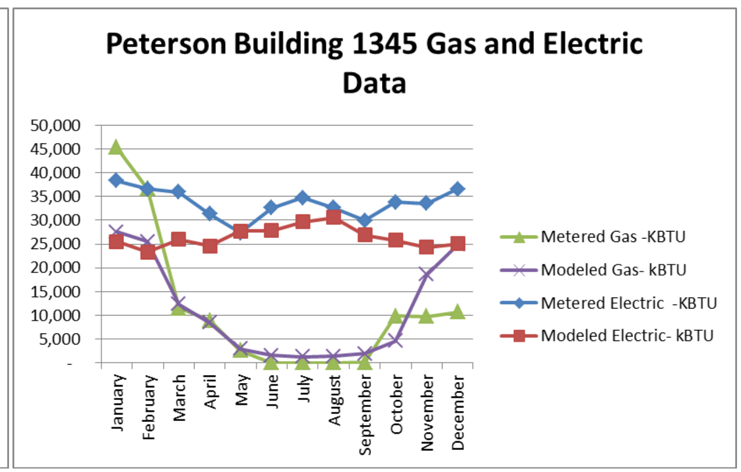
MONTHLY GAS AND ELECTRIC CHARTS

Offices (continued):





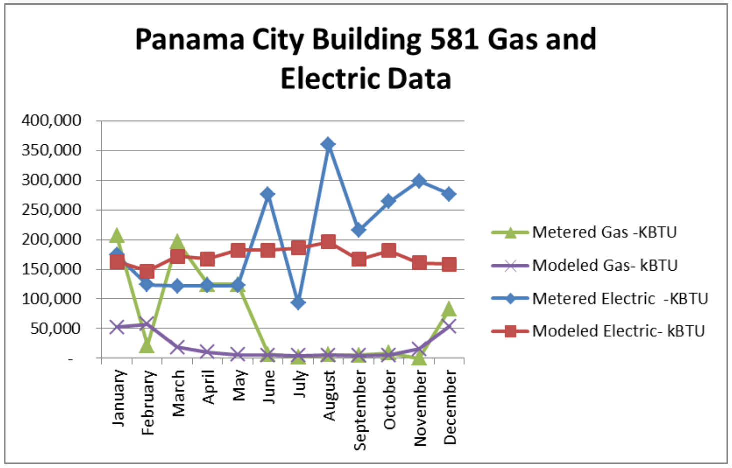


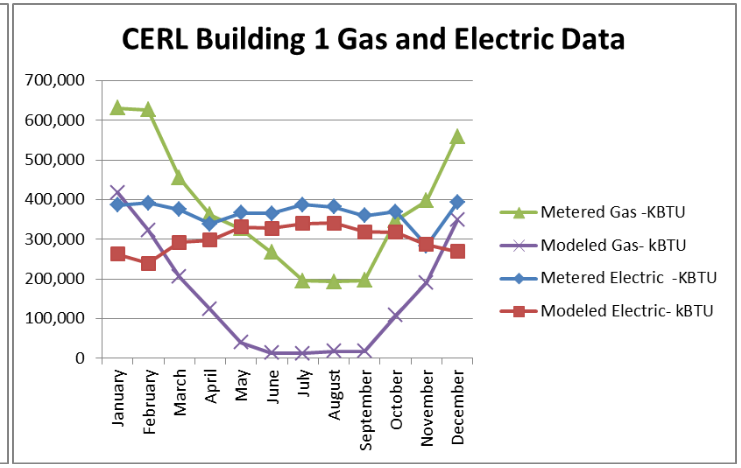


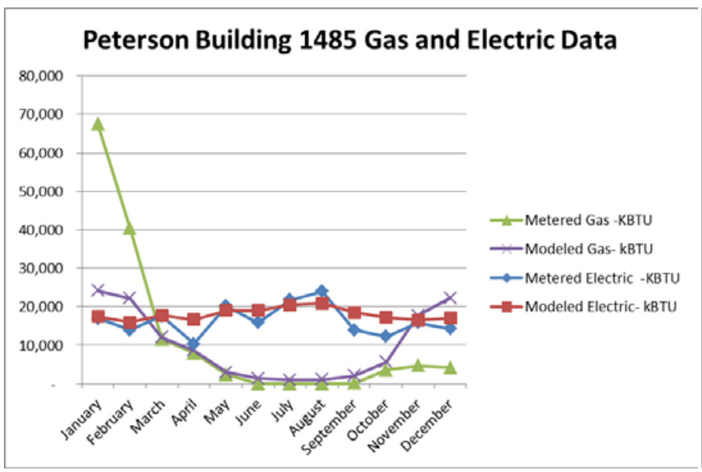
APPENDIX C (continued)

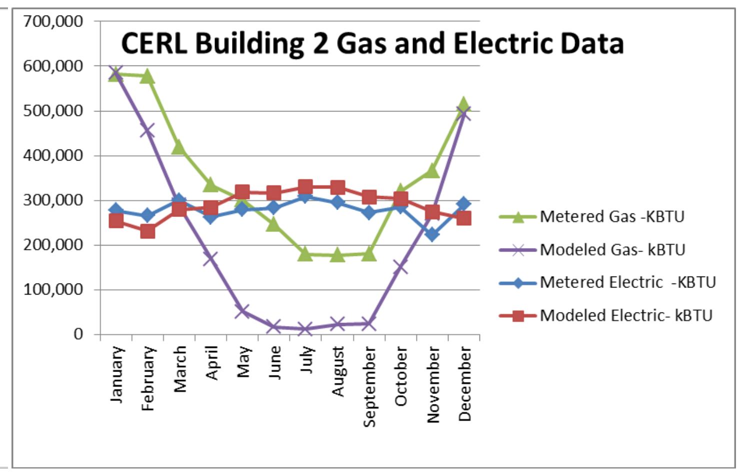
MONTHLY GAS AND ELECTRIC CHARTS

Offices (continued):





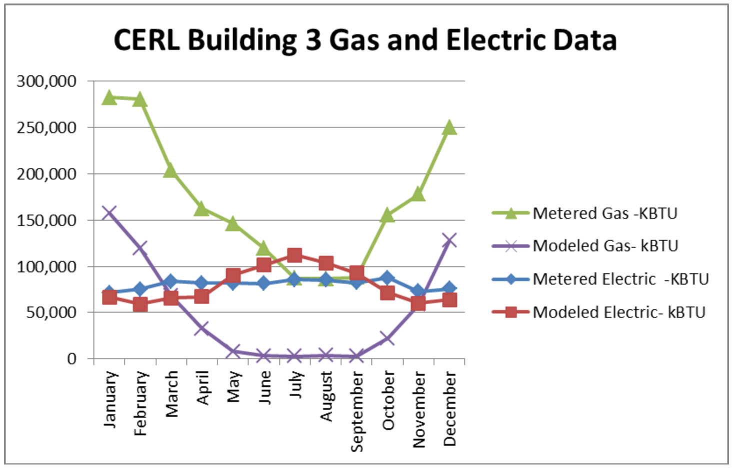




APPENDIX C (continued)

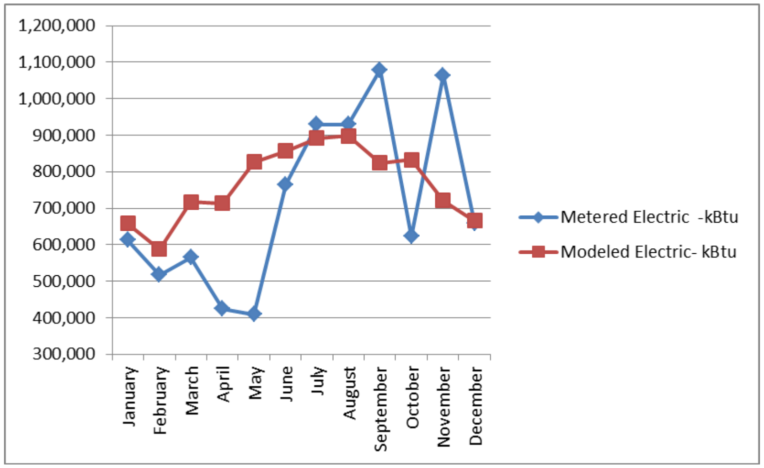
MONTHLY GAS AND ELECTRIC CHARTS

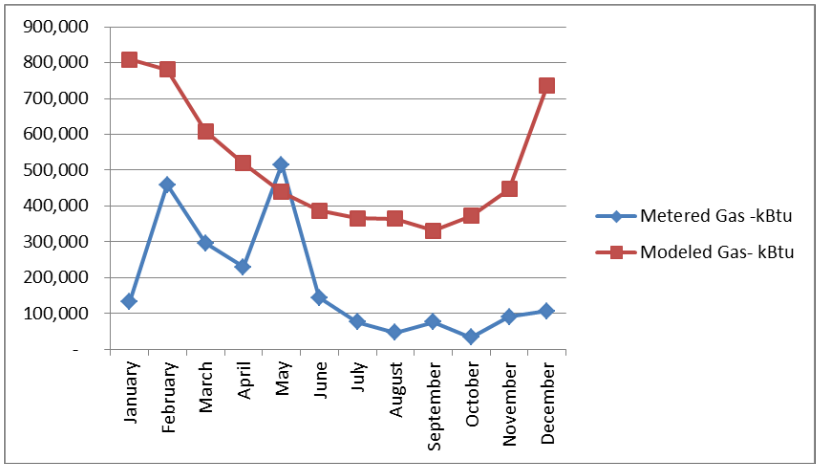
Offices (continued):



Barracks Buildings:

Dorm 484 Panama City, Florida



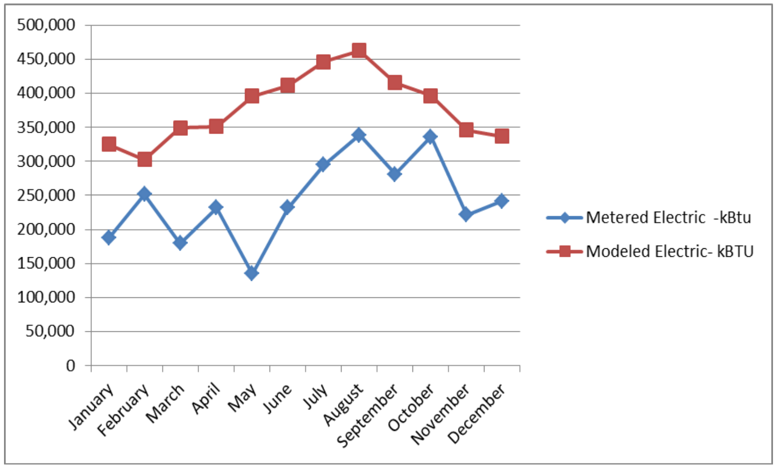


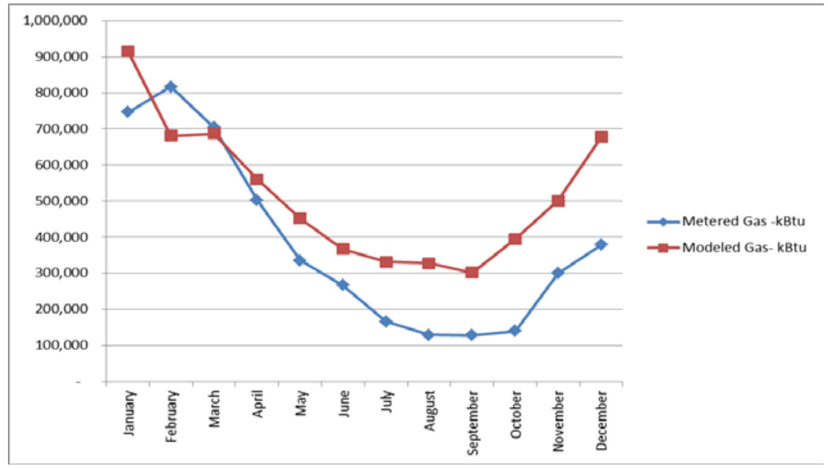
APPENDIX C (continued)

MONTHLY GAS AND ELECTRIC CHARTS

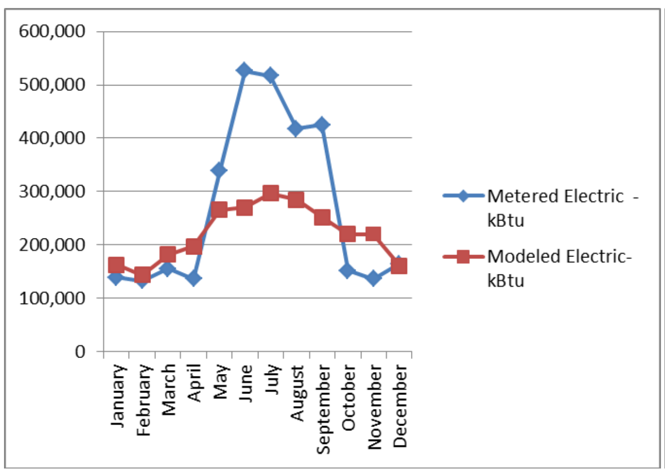
Barracks Buildings (continued):

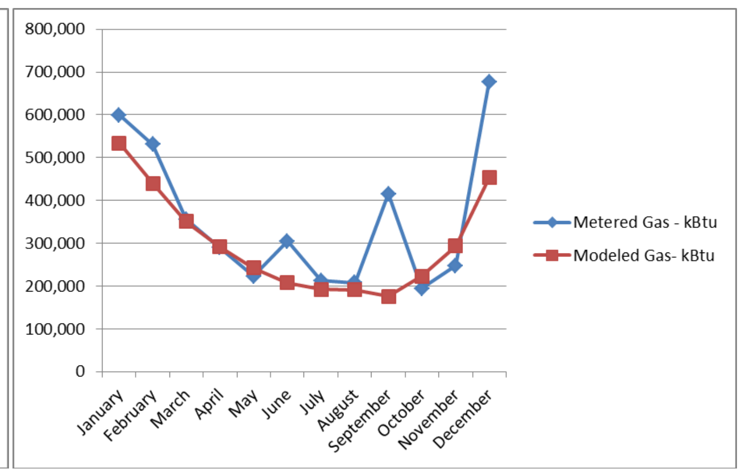
Dorm 373 Portsmouth Naval Base





Dorm 831 Fort Leonard Wood



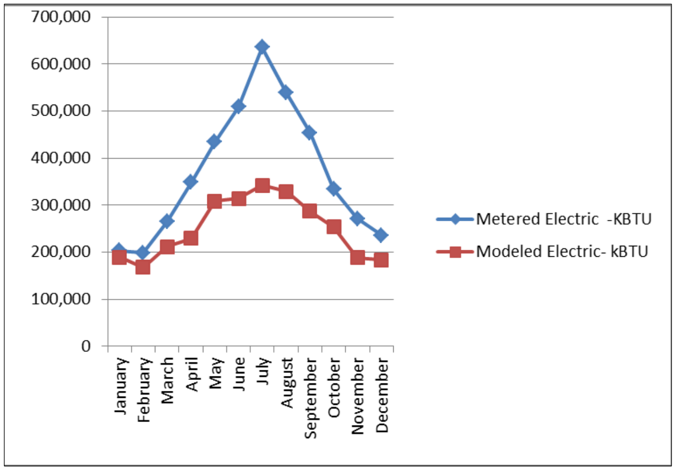


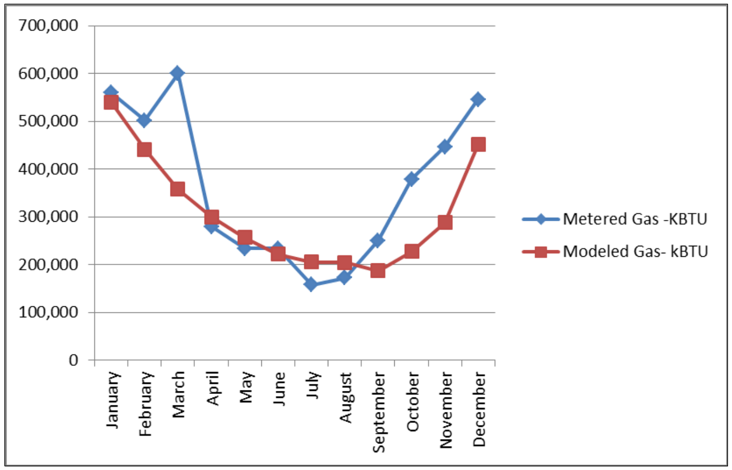
APPENDIX C (continued)

MONTHLY GAS AND ELECTRIC CHARTS

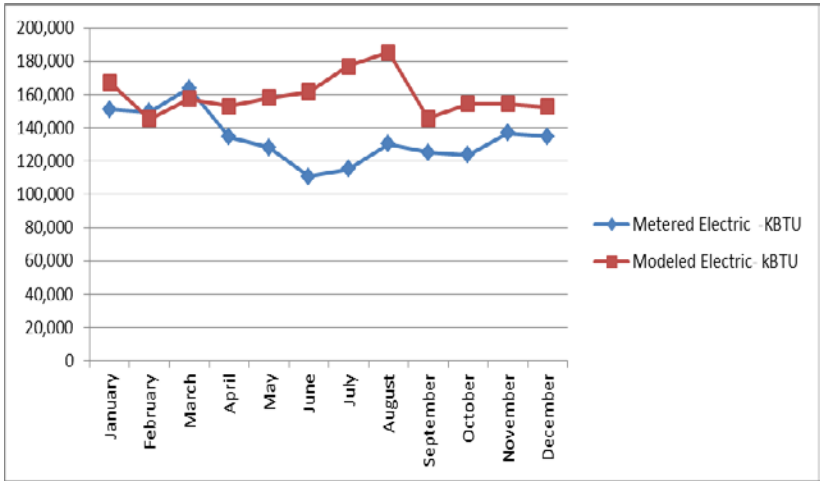
Barracks Buildings (continued):

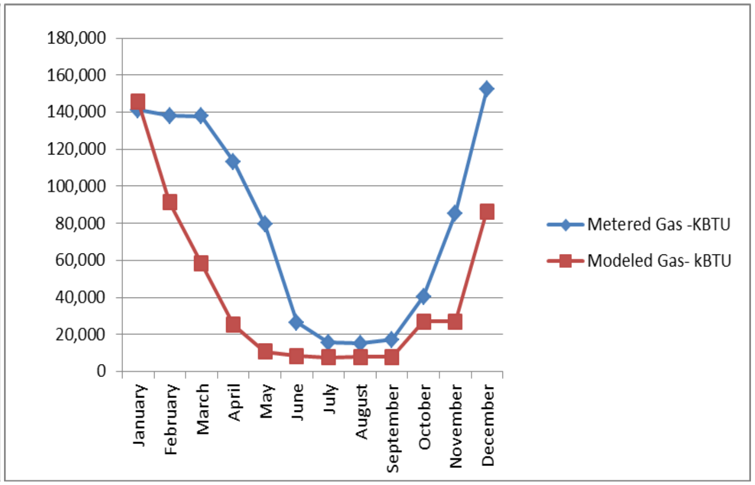
Dorm 937 Fort Leonard Wood





Dorm 9136 Joint Base Lewis McChord



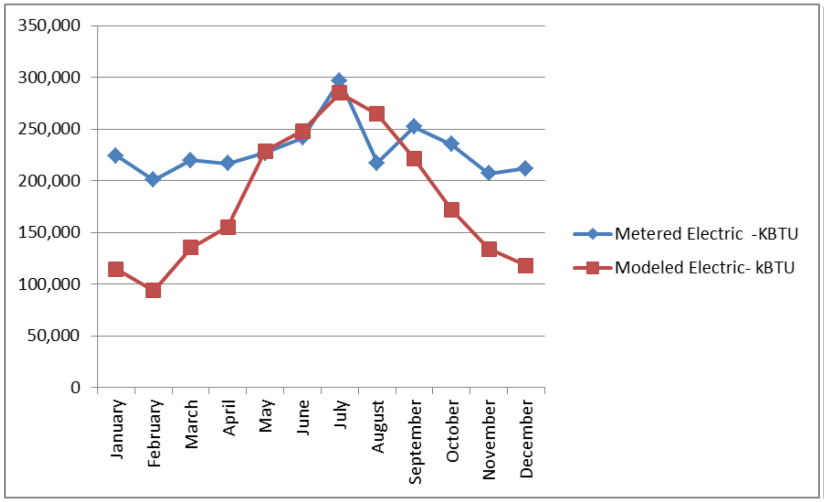


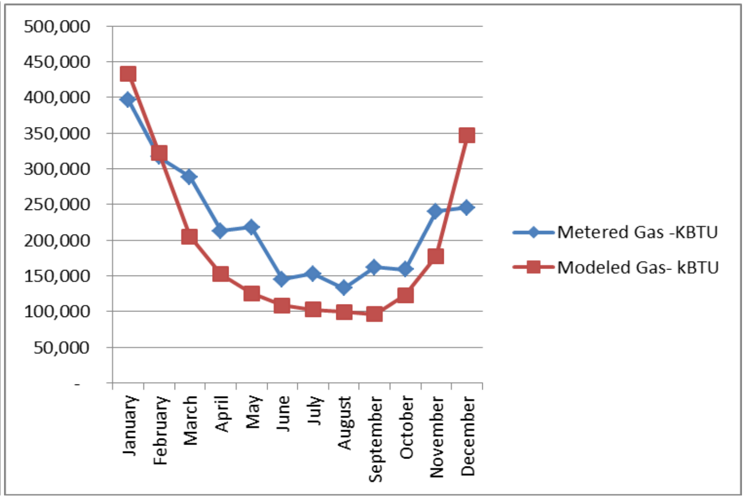
APPENDIX C (continued)

MONTHLY GAS AND ELECTRIC CHARTS

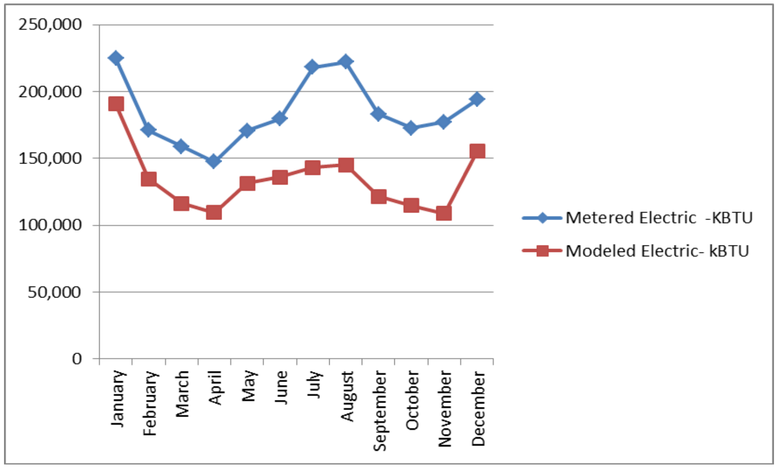
Specialty Use Buildings:

Cafeteria 3650, Seymour Air Force Base





School Building 4103, Seymour Air Force Base

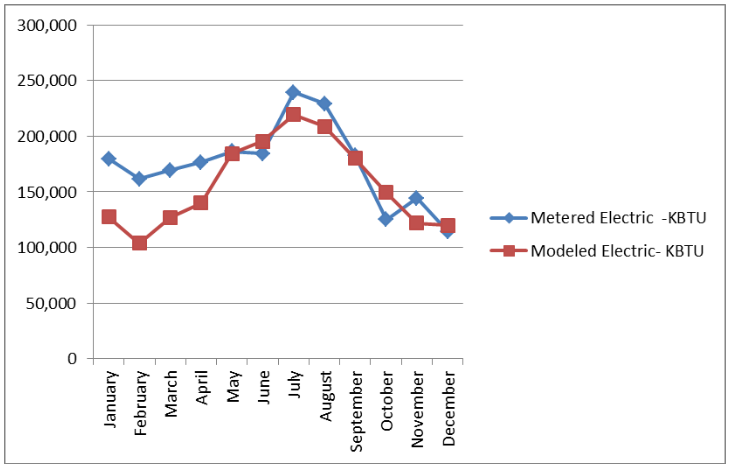


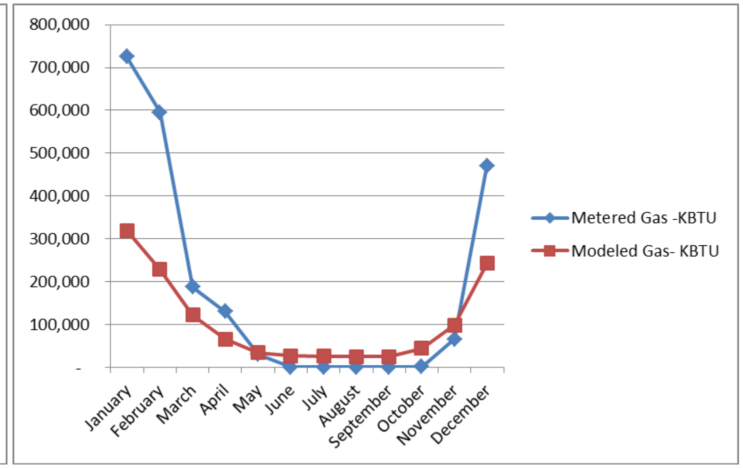
APPENDIX C (continued)

MONTHLY GAS AND ELECTRIC CHARTS

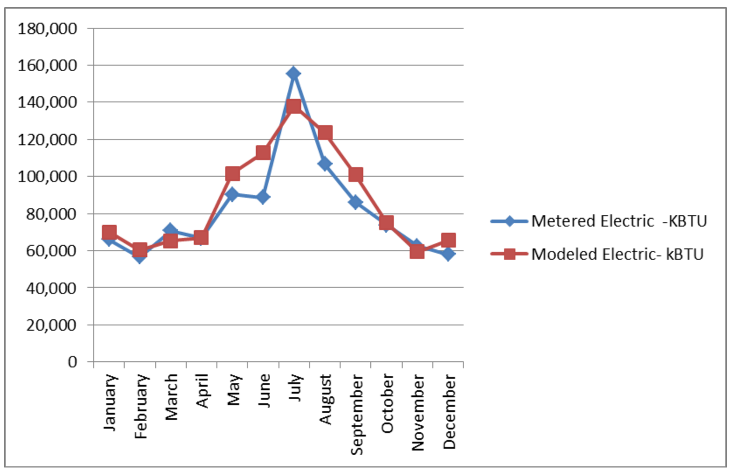
Specialty Use Buildings (continued):

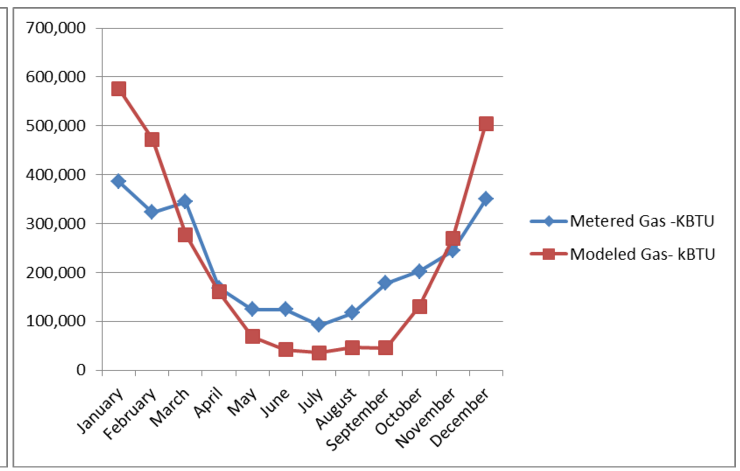
Automotive Facility 4537, Seymour Air Force Base





Gym Building 640, Fort Leonard Wood





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